

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON PAGE TWO OF THE FORM.)

I. (a) PLAINTIFFS

JDS UNIPHASE CORPORATION, a Delaware corporation

DEFENDANTS

SYNTUNE, AB, a Swedish corporation; CYOPTICS, INC., a Delaware corporation

(b) County of Residence of First Listed Plaintiff (IN U.S. PLAINTIFF CASES)
(EXCEPT IN U.S. PLAINTIFF CASES)

County of Residence of First Listed Defendant
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE LAND INVOLVED.

(c) Attorney's (Firm Name, Address, and Telephone Number)

Heather N. Mewes (CSB No. 203690)
Lauren E. Whittmore (CSB No. 255432)
Fenwick & West, LLP
55 California Street, 12th Floor, San Francisco, CA 94104 (415) 875-2300

Attorneys (If Known)

C08 03498 JL

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- ☐ 1 U.S. Government Plaintiff ☒ 3 Federal Question (U.S. Government Not a Party)
☐ 2 U.S. Government Defendant ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant)

- | | PTF | DEF | | PTF | DEF |
|---|----------------------------|----------------------------|---|----------------------------|----------------------------|
| Citizen of This State | <input type="checkbox"/> 1 | <input type="checkbox"/> 1 | Incorporated or Principal Place of Business In This State | <input type="checkbox"/> 4 | <input type="checkbox"/> 4 |
| Citizen of Another State | <input type="checkbox"/> 2 | <input type="checkbox"/> 2 | Incorporated and Principal Place of Business In Another State | <input type="checkbox"/> 5 | <input type="checkbox"/> 5 |
| Citizen or Subject of a Foreign Country | <input type="checkbox"/> 3 | <input type="checkbox"/> 3 | Foreign Nation | <input type="checkbox"/> 6 | <input type="checkbox"/> 6 |

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT	TORTS	FORFEITURE/PENALTY	BANKRUPTCY	OTHER STATUTES				
<input type="checkbox"/> 110 Insurance <input type="checkbox"/> 120 Marine <input type="checkbox"/> 130 Miller Act <input type="checkbox"/> 140 Negotiable Instrument <input type="checkbox"/> 150 Recovery of Overpayment & Enforcement of Judgment <input type="checkbox"/> 151 Medicare Act <input type="checkbox"/> 152 Recovery of Defaulted Student Loans (Excl. Veterans) <input type="checkbox"/> 153 Recovery of Overpayment of Veteran's Benefits <input type="checkbox"/> 160 Stockholders' Suits <input type="checkbox"/> 190 Other Contract <input type="checkbox"/> 195 Contract Product Liability <input type="checkbox"/> 196 Franchise	<table border="1"><thead><tr><th>PERSONAL INJURY</th><th>PERSONAL INJURY</th></tr></thead><tbody><tr><td><input type="checkbox"/> 310 Airplane <input type="checkbox"/> 315 Airplane Product Liability <input type="checkbox"/> 320 Assault, Libel & Slander <input type="checkbox"/> 330 Federal Employers' Liability <input type="checkbox"/> 340 Marine <input type="checkbox"/> 345 Marine Product Liability <input type="checkbox"/> 350 Motor Vehicle <input type="checkbox"/> 355 Motor Vehicle Product Liability <input type="checkbox"/> 360 Other Personal Injury</td><td><input type="checkbox"/> 362 Personal Injury—Med. Malpractice <input type="checkbox"/> 365 Personal Injury—Product Liability <input type="checkbox"/> 368 Asbestos Personal Injury Product Liability PERSONAL PROPERTY <input type="checkbox"/> 370 Other Fraud <input type="checkbox"/> 371 Truth in Lending <input type="checkbox"/> 380 Other Personal Property Damage <input type="checkbox"/> 385 Property Damage Product Liability</td></tr></tbody></table>	PERSONAL INJURY	PERSONAL INJURY	<input type="checkbox"/> 310 Airplane <input type="checkbox"/> 315 Airplane Product Liability <input type="checkbox"/> 320 Assault, Libel & Slander <input type="checkbox"/> 330 Federal Employers' Liability <input type="checkbox"/> 340 Marine <input type="checkbox"/> 345 Marine Product Liability <input type="checkbox"/> 350 Motor Vehicle <input type="checkbox"/> 355 Motor Vehicle Product Liability <input type="checkbox"/> 360 Other Personal Injury	<input type="checkbox"/> 362 Personal Injury—Med. Malpractice <input type="checkbox"/> 365 Personal Injury—Product Liability <input type="checkbox"/> 368 Asbestos Personal Injury Product Liability PERSONAL PROPERTY <input type="checkbox"/> 370 Other Fraud <input type="checkbox"/> 371 Truth in Lending <input type="checkbox"/> 380 Other Personal Property Damage <input type="checkbox"/> 385 Property Damage Product Liability	<input type="checkbox"/> 610 Agriculture <input type="checkbox"/> 620 Other Food & Drug <input type="checkbox"/> 625 Drug Related Seizure of Property 21 USC 881 <input type="checkbox"/> 630 Liquor Laws <input type="checkbox"/> 640 R.R. & Truck <input type="checkbox"/> 650 Airline Regs. <input type="checkbox"/> 660 Occupational Safety/Health <input type="checkbox"/> 690 Other	<input type="checkbox"/> 422 Appeal 28 USC 158 <input type="checkbox"/> 423 Withdrawal 28 USC 157 PROPERTY RIGHTS <input type="checkbox"/> 820 Copyrights <input checked="" type="checkbox"/> 830 Patent <input type="checkbox"/> 840 Trademark	<input type="checkbox"/> 400 State Reapportionment <input type="checkbox"/> 410 Antitrust <input type="checkbox"/> 430 Banks and Banking <input type="checkbox"/> 450 Commerce <input type="checkbox"/> 460 Deportation <input type="checkbox"/> 470 Racketeer Influenced and Corrupt Organizations <input type="checkbox"/> 480 Consumer Credit <input type="checkbox"/> 490 Cable/Sat TV <input type="checkbox"/> 810 Selective Service <input type="checkbox"/> 850 Securities/Commodities/Exchange <input type="checkbox"/> 875 Customer Challenge 12 USC 3410 <input type="checkbox"/> 890 Other Statutory Actions <input type="checkbox"/> 891 Agricultural Acts <input type="checkbox"/> 892 Economic Stabilization Act <input type="checkbox"/> 893 Environmental Matters <input type="checkbox"/> 894 Energy Allocation Act <input type="checkbox"/> 895 Freedom of Information Act <input type="checkbox"/> 900 Appeal of Fee Determination Under Equal Access to Justice <input type="checkbox"/> 950 Constitutionality of State Statutes
PERSONAL INJURY	PERSONAL INJURY							
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REAL PROPERTY <input type="checkbox"/> 210 Land Condemnation <input type="checkbox"/> 220 Foreclosure <input type="checkbox"/> 230 Rent Lease & Ejectment <input type="checkbox"/> 240 Torts to Land <input type="checkbox"/> 245 Tort Product Liability <input type="checkbox"/> 290 All Other Real Property	CIVIL RIGHTS <input type="checkbox"/> 441 Voting <input type="checkbox"/> 442 Employment <input type="checkbox"/> 443 Housing/Accommodations <input type="checkbox"/> 444 Welfare <input type="checkbox"/> 445 Amer. w/Disabilities - Employment <input type="checkbox"/> 446 Amer. w/Disabilities - Other <input type="checkbox"/> 440 Other Civil Rights	PRISONER PETITIONS <input type="checkbox"/> 510 Motions to Vacate Sentence Habeas Corpus: <input type="checkbox"/> 530 General <input type="checkbox"/> 535 Death Penalty <input type="checkbox"/> 540 Mandamus & Other <input type="checkbox"/> 550 Civil Rights <input type="checkbox"/> 555 Prison Condition	LABOR <input type="checkbox"/> 710 Fair Labor Standards Act <input type="checkbox"/> 720 Labor/Mgmt. Relations <input type="checkbox"/> 730 Labor/Mgmt. Reporting & Disclosure Act <input type="checkbox"/> 740 Railway Labor Act <input type="checkbox"/> 790 Other Labor Litigation <input type="checkbox"/> 791 Empl. Ret. Inc. Security Act IMMIGRATION <input type="checkbox"/> 462 Naturalization Application <input type="checkbox"/> 463 Habeas Corpus - Alien Detainee <input type="checkbox"/> 465 Other Immigration Actions	SOCIAL SECURITY <input type="checkbox"/> 861 HIA (1395ff) <input type="checkbox"/> 862 Black Lung (923) <input type="checkbox"/> 863 DIWC/DIWW (405(g)) <input type="checkbox"/> 864 SSID Title XVI <input type="checkbox"/> 865 RSI (405(g)) FEDERAL TAX SUITS <input type="checkbox"/> 870 Taxes (U.S. Plaintiff or Defendant) <input type="checkbox"/> 871 IRS—Third Party 26 USC 7609				

V. ORIGIN

(Place an "X" in One Box Only)

- ☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

Cite the U.S. Civil Statute under which you are filing (Do not cite jurisdictional statutes unless diversity):

VI. CAUSE OF ACTION

Brief description of cause:

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23 **DEMAND \$**

CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

PLEASE REFER TO CIVIL L.R. 3-12 CONCERNING REQUIREMENT TO FILE "NOTICE OF RELATED CASE". CV-08-01275-RMW

IX. DIVISIONAL ASSIGNMENT (CIVIL L.R. 3-2) (PLACE AND "X" IN ONE BOX ONLY)

☐ SAN FRANCISCO/OAKLAND ☒ SAN JOSE

DATE

7/21/08

SIGNATURE OF ATTORNEY OF RECORD

Heather N. Mewes / LEW

ORIGINAL

UNITED STATES DISTRICT COURT

for the

NORTHERN DISTRICT OF CALIFORNIA

JDS UNIPHASE, a Delaware corporation

Plaintiff

v.

SYNTUNE, AB, a Swedish corporation;
CYOPTICS, INC., a Delaware corporation

Defendant

E-FILING

ADR

Civil Action No.

C08 03498 JL

Summons in a Civil Action

To: Syntune, AB, Torghamnsgatan 30A, S-164 40 Kista, Sweden

(Defendant's name)

A lawsuit has been filed against you.

Within 20 days after service of this summons on you (not counting the day you received it), you must serve on the plaintiff an answer to the attached complaint or a motion under Rule 12 of the Federal Rules of Civil Procedure. The answer or motion must be served on the plaintiff's attorney, whose name and address are:

HEATHER N. MEWES (CSB No. 203690)
LAURENT E. WHITTEMORE (CSB No. 255432)
FENWICK & WEST LLP
555 California Street, 12th Floor
San Francisco, California 94104

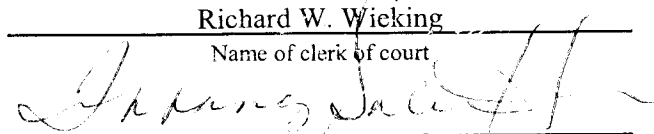
If you fail to do so, judgment by default will be entered against you for the relief demanded in the complaint. You also must file your answer or motion with the court.

JUL 21 2008

Date: _____

Richard W. Wieking

Name of clerk of court



Deputy clerk's signature

Tiffany Salinas-Harwell

(Use 60 days if the defendant is the United States or a United States agency, or is an officer or employee of the United States allowed 60 days by Rule 12(a)(3).)

ORIGINAL

UNITED STATES DISTRICT COURT

for the

NORTHERN DISTRICT OF CALIFORNIA

JDS UNIPHASE, a Delaware corporation

Plaintiff

v.

SYNTUNE, AB, a Swedish corporation;
CYOPTICS, INC., a Delaware corporation

Defendant

Civil Action No. C 08-03498-JL

AMENDED

Summons in a Civil Action

To: Cyoptics, Inc., 9999 Hamilton Blvd., Breingsville, PA 18031

(Defendant's name)

A lawsuit has been filed against you.

Within 20 days after service of this summons on you (not counting the day you received it), you must serve on the plaintiff an answer to the attached complaint or a motion under Rule 12 of the Federal Rules of Civil Procedure. The answer or motion must be served on the plaintiff's attorney, whose name and address are:

Heather N. Mewes (CBS No. 203690)
Lauren E. Whittemore (CBS No. 255432)
Fenwick & West LLP
555 California Street, 12th Floor
San Francisco, CA 94104

If you fail to do so, judgment by default will be entered against you for the relief demanded in the complaint. You also must file your answer or motion with the court.

Date: JUL 23 2008

Richard W. Wieking

Name of clerk of court

Deputy clerk's signature

Tiffany Salinas-Harwell

(Use 60 days if the defendant is the United States or a United States agency, or is an officer or employee of the United States allowed 60 days by Rule 12(a)(3).)

1 HEATHER N. MEWES (CSB No. 203690)
2 hmewes@fenwick.com
3 LAUREN E. WHITEMORE (CSB No. 255432)
4 lwhitemore@fenwick.com
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555 California Street, 12th Floor
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Telephone: 415-875-2300
Facsimile: 415-281.1350

6 Attorneys for Plaintiff
7 JDS Uniphase Corporation

E-FILING

ADR

ORIGINAL FILED

JUL 21 2008

Richard W. Wieking
Clerk, U.S. District Court
Northern District of California
San Jose

8
9 **UNITED STATES DISTRICT COURT**
10 **NORTHERN DISTRICT OF CALIFORNIA**
11 **SAN JOSE DIVISION**

12 JDS UNIPHASE, a Delaware Corporation,

13 Plaintiff,

14 v.

15 SYNTUNE, AB, a Swedish corporation;
16 CYOPTICS, INC., a Delaware corporation

17 Defendants.

C08 03498

JL

**COMPLAINT FOR PATENT
INFRINGEMENT**

DEMAND FOR JURY TRIAL

18
19 Plaintiff JDS UNIPHASE CORPORATION (hereinafter "JDSU"), by and through its
20 undersigned counsel, for its complaint herein, alleges as follows:

21 **PARTIES**

22 1. Defendant JDSU is a corporation duly incorporated and existing under the laws of the
23 State of Delaware, with its principal place of business in Milpitas, California.

24 2. On information and belief, Cyoptics, Inc. ("Cyoptics") is a corporation organized and
25 existing under the laws of the State of Delaware, with its principal place of business at 9999
26 Hamilton Blvd., Breinigsville, PA 18031.

12. On February 3, 2004, the United States Patent and Trademark Office issued patent number 6,687,278 (the "'278 Patent"). A copy of the '278 Patent is attached as Exhibit 3.

13. The '035 Patent, the '400 Patent, and the '278 Patent were assigned to Agility Communications, Inc.

14. In 2005, JDSU acquired Agility Communications, Inc., and all of its assets, including the '035 Patent, the '400 Patent, and the '278 Patent.

15. The '035 Patent, the '400 Patent, and the '278 Patent generally pertain to the invention of tunable lasers with integrated optical amplifiers and a common waveguide.

CLAIM AGAINST CYOPTICS FOR PATENT INFRINGEMENT

16. From a time not yet known, Cyoptics, without a license or any other right recognized by law, has infringed one or more claims of the '035 patent. Cyoptics' infringing conduct includes one or more of the following:

a. the manufacture, use, sale, offer for sale, and/or importation into the United States of tunable laser products covered by one or more claims of the '035 patent;

b. actively inducing the manufacture, use, sale, offer for sale, and/or importation into the United States of tunable laser products covered by one or more claims of the '035 patent;

c. contributing to the manufacture, use, sale, offer for sale, and/or importation into the United States of tunable laser products covered by one or more claims of the '035 patent;

d. supplying or causing to be supplied in or from the United States all or a substantial portion of the components of the tunable laser claimed in the '035 patent, where such components are uncombined in whole or in part, in such manner as to actively induce the combination of such components outside of the United States in a manner that would infringe the '035 patent if such combination occurred within the United States; and/or

e. supplying or causing to be supplied in or from the United States one or more components of the tunable laser claimed in the '035 patent that are especially made or especially adapted for use in the claimed tunable laser of the '035 patent and are not a staple article or

1 commodity of commerce suitable for substantial non-infringing use, where such components are
2 uncombined in whole or in part, knowing that such components are so especially made or adapted
3 and intending that such components will be combined outside of the United States in a manner that
4 would infringe the '035 patent if such combination occurred within the United States.

5 17. On information and belief, Cyoptics manufactures and sells tunable laser products
6 designed by Syntune, which are covered by the claims of the '035 Patent.

7 18. Cyoptics, through its acts recited in Paragraphs 16 & 17, also infringes one or more
8 claims of the '400 Patent and the '278 Patent.

9 19. On information and belief, Cyoptics will continue infringing the claims of the '035,
10 '400, and '278 Patents unless enjoined by the Court.

11 20. Cyoptics' infringement of the claims of the '035, '400, and '278 Patents has caused
12 and will continue to cause JDSU substantial and irreparable injury, for which JDSU is entitled to all
13 relief provided for by 35 U.S.C. §§ 281, 283, 284 & 285, including, but not limited to, injunctive
14 relief, compensatory damages not less than the amount of a reasonable royalty, interest, costs, and
15 reasonable attorney fees where appropriate.

16 **CLAIM AGAINST SYNTUNE FOR PATENT INFRINGEMENT**

17 21. From a time not yet known, Syntune, without a license or any other right recognized
18 by law, has infringed one or more claims of the '035 patent. Syntune's infringing conduct includes
19 one or more of the following:

- 20 a. the manufacture, use, sale, offer for sale, and/or importation into the United
21 States of tunable laser products covered by one or more claims of the '035 patent;
22 b. actively inducing the manufacture, use, sale, offer for sale, and/or importation
23 into the United States of tunable laser products covered by one or more claims of the '035 patent;
24 c. contributing to the manufacture, use, sale, offer for sale, and/or importation
25 into the United States of tunable laser products covered by one or more claims of the '035 patent;

e. supplying or causing to be supplied in or from the United States one or more components of the tunable laser claimed in the '035 patent that are especially made or especially adapted for use in the tunable laser claimed in the '035 patent and are not a staple article or commodity of commerce suitable for substantial non-infringing use, where such components are uncombined in whole or in part, knowing that such components are so especially made or adapted and intending that such components will be combined outside of the United States in a manner that would infringe the '035 patent if such combination occurred within the United States.

23. Syntune, through its acts recited in Paragraphs 21–22, also infringes one or more claims of the ‘400 Patent and the ‘278 Patent.

25. Syntune's infringement of the claims of the '035, '400, and '278 Patents has caused and will continue to cause JDSU substantial and irreparable injury, for which JDSU is entitled to all relief provided for by 35 U.S.C. §§ 281, 283, 284 & 285, including, but not limited to, injunctive relief, compensatory damages not less than the amount of a reasonable royalty, interest, costs, and reasonable attorney fees where appropriate.

WHEREFORE, Defendants request that this Court:

1 A. Find that Cyoptics and Syntune have infringed and are infringing the claims of the
2 '035, '400, and '278 Patents.

3 B. Award JDSU its compensatory damages resulting from Cyoptics and Syntune's
4 infringement, together with interest as fixed by the court;

5 C. Issue an injunction enjoining Cyoptics and Syntune, their employees, agents, and all
6 others acting in concert with Cyoptics and/or Syntune from further infringement of the claims of the
7 '035, '400, and '278 Patents; and

8 D. Grant such other and further relief as the court may find just and proper, including
9 reasonable attorneys fees where appropriate.

10
11 Dated: July 21, 2008

FENWICK & WEST LLP

12
13 By: Heather N. Mewes / LEW
14 Heather N. Mewes
15 FENWICK & WEST LLP
16 555 California Street, 12th Floor
San Francisco, California 94104
Telephone: 415-875-2300
Facsimile: 415-281.1350

17 Attorneys for Plaintiff
18 JDS UNIPHASE CORPORATION.

19
20 **DEMAND FOR JURY TRIAL**

21 Pursuant to Rule 38 of the Federal Rules of Civil Procedure, Plaintiffs demand a trial by jury
22 on all issues so triable.

1 Dated: July 21, 2008

FENWICK & WEST LLP

2 By: Heather N. Mewes / LEW

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4 FENWICK & WEST LLP
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9 Attorneys for Plaintiff
10 JDS UNIPHASE CORPORATION
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EXHIBIT 1



US006658035B1

(12) **United States Patent**
Mason et al.

(10) Patent No.: **US 6,658,035 B1**
(45) Date of Patent: ***Dec. 2, 2003**

(54) **TUNABLE LASER SOURCE WITH
INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ
(US); **Gregory Fish**, Santa Barbara, CA
(US); **Larry Coldren**, Santa Barbara,
CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta,
CA (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 243 days.

This patent is subject to a terminal dis-
claimer.

(21) Appl. No.: **09/614,375**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

- (63) Continuation-in-part of application No. 09/614,377, filed on
Jul. 12, 2000, which is a continuation-in-part of application
No. 09/614,895, filed on Jul. 12, 2000, now Pat. No.
6,349,106, which is a continuation-in-part of application No.
09/614,378, filed on Jul. 12, 2000, which is a continuation-
in-part of application No. 09/614,376, filed on Jul. 12, 2000,
which is a continuation-in-part of application No. 09/614,
674, filed on Jul. 12, 2000, which is a continuation-in-part of
application No. 09/614,195, filed on Jul. 12, 2000, which is
a continuation-in-part of application No. 09/614,665, filed
on Jul. 12, 2000, which is a continuation-in-part of appli-
cation No. 09/614,224, filed on Jul. 12, 2000.
- (60) Provisional application No. 60/152,072, filed on Sep. 2,
1999, provisional application No. 60/152,049, filed on Sep.
2, 1999, and provisional application No. 60/152,038, filed
on Sep. 2, 1999.

- (51) Int. Cl.⁷ **H01S 5/026**
(52) U.S. Cl. **372/50; 372/43**
(58) Field of Search **372/50, 43**

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(List continued on next page.)

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Primary Examiner—Paul Ip

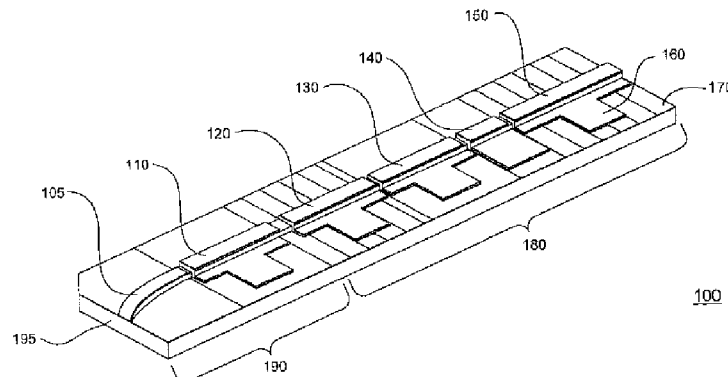
Assistant Examiner—Jeffrey N. Zahn

(74) Attorney, Agent, or Firm—Gates & Cooper LLP

(57) **ABSTRACT**

A laser assembly includes an epitaxial structure formed on
a substrate. A separately controllable tunable laser resonator
and external optical amplifier are formed in the epitaxial
structure. At least a portion of the laser and amplifier share
a common waveguide, which may have non-uniform optical
or geometrical properties along the waveguide centerline or
across a normal to the centerline.

82 Claims, 7 Drawing Sheets



US 6,658,035 B1

Page 2

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* cited by examiner

U.S. Patent

Dec. 2, 2003

Sheet 1 of 7

US 6,658,035 B1

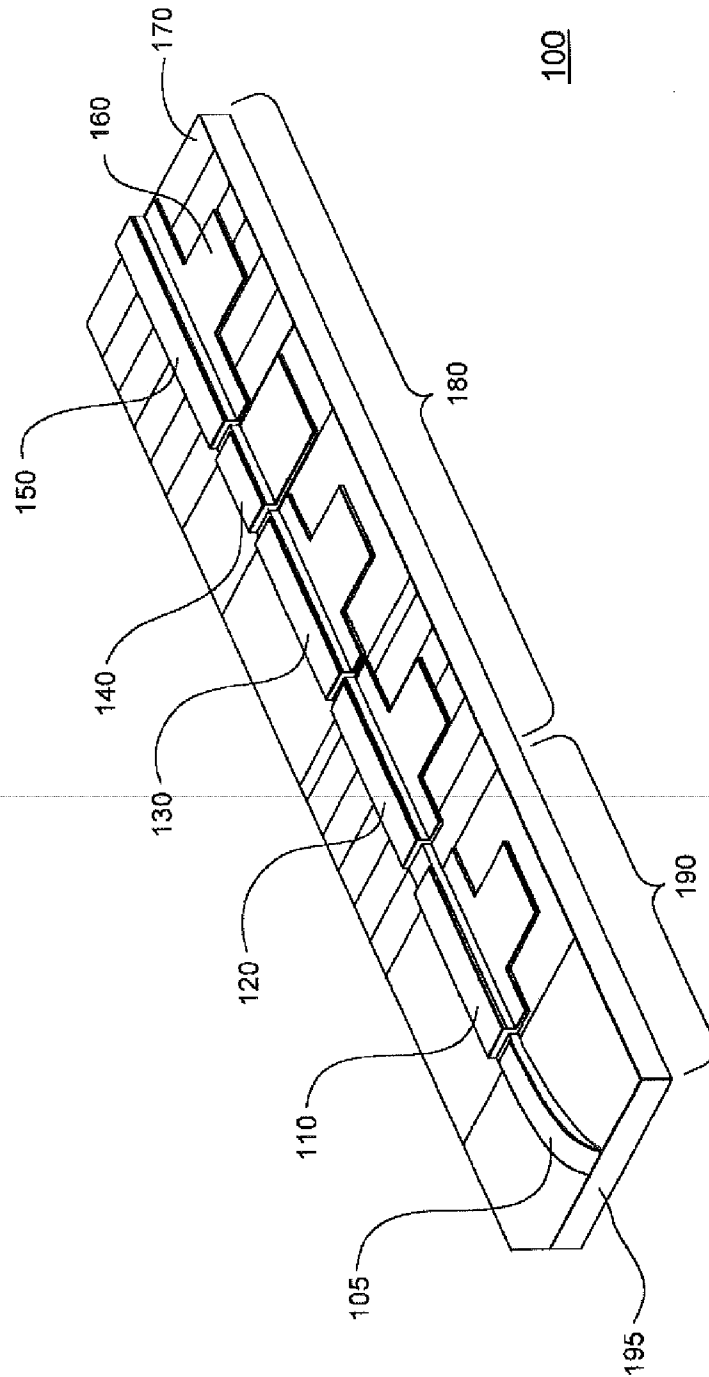


FIG. 1A

U.S. Patent

Dec. 2, 2003

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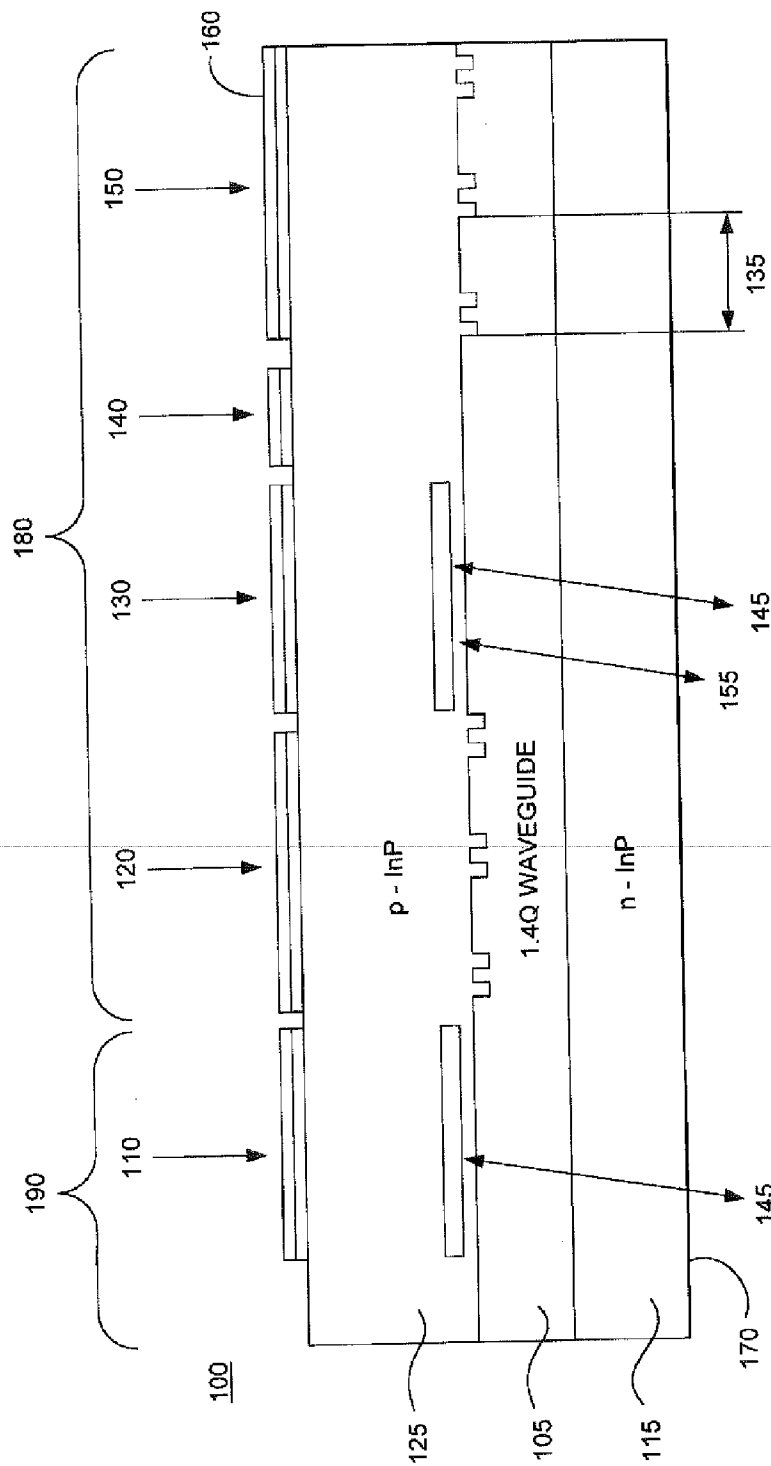


FIG. 1B

U.S. Patent

Dec. 2, 2003

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US 6,658,035 B1

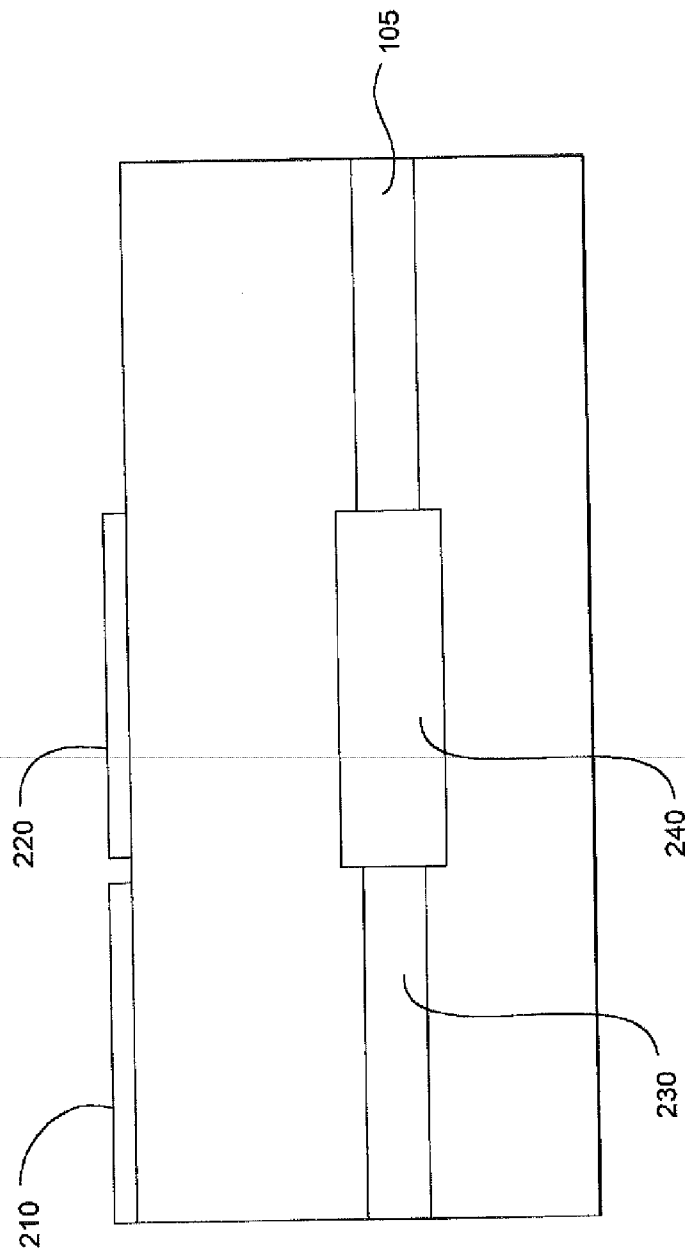


FIG. 2A

U.S. Patent

Dec. 2, 2003

Sheet 4 of 7

US 6,658,035 B1

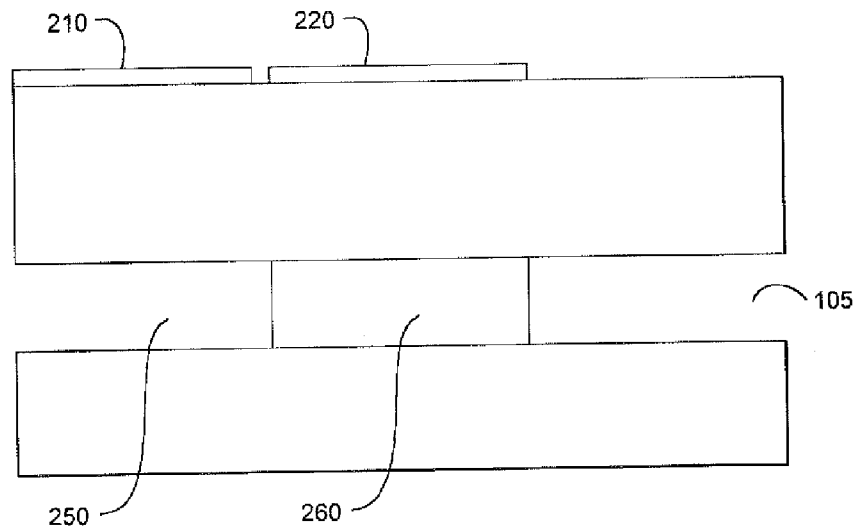


FIG. 2B

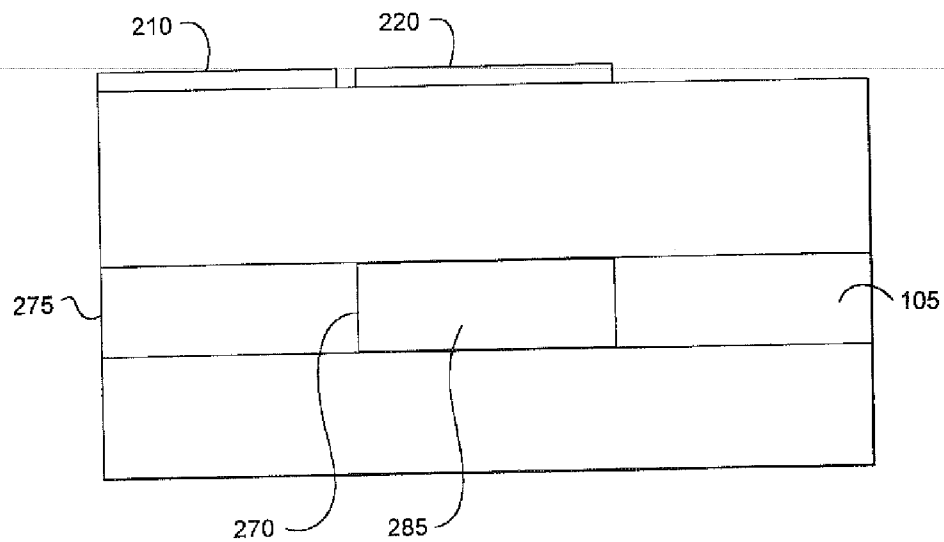


FIG. 2C

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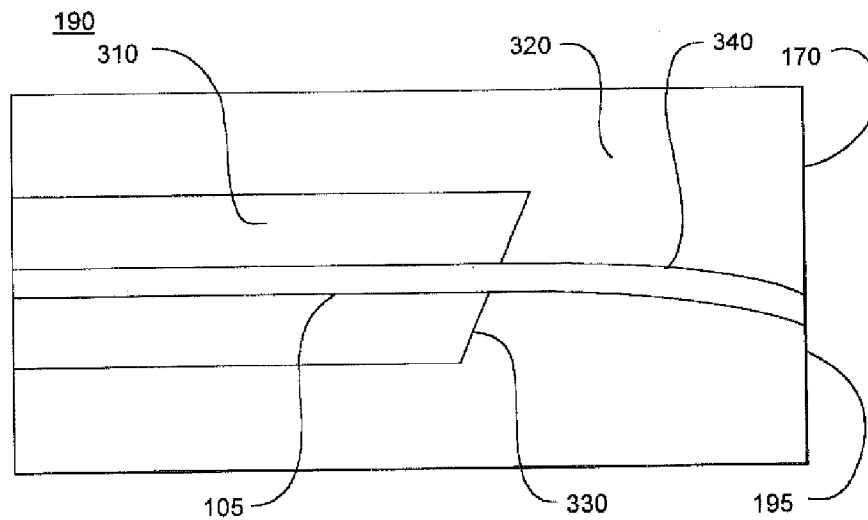


FIG. 3A

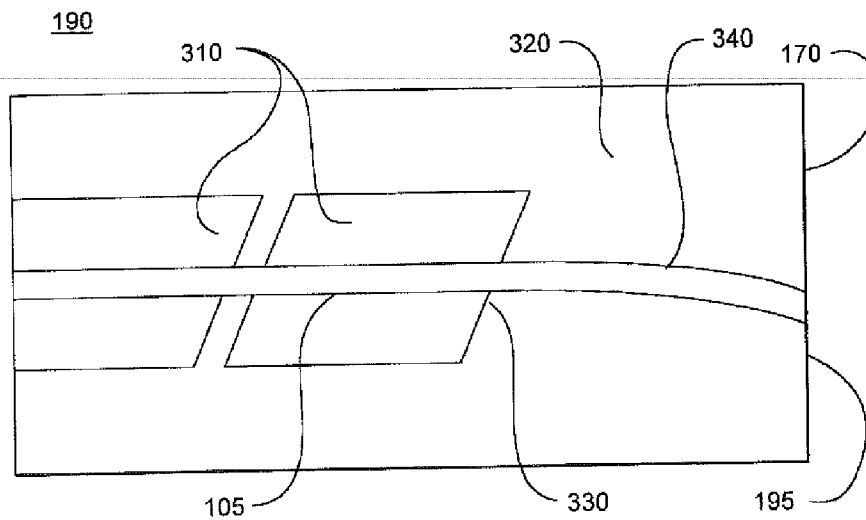


FIG. 3B

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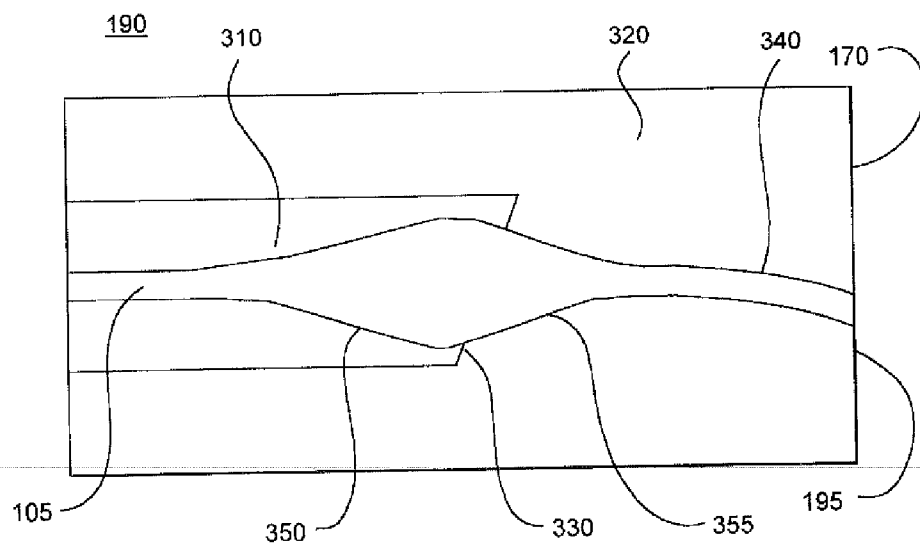


FIG. 3C

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190

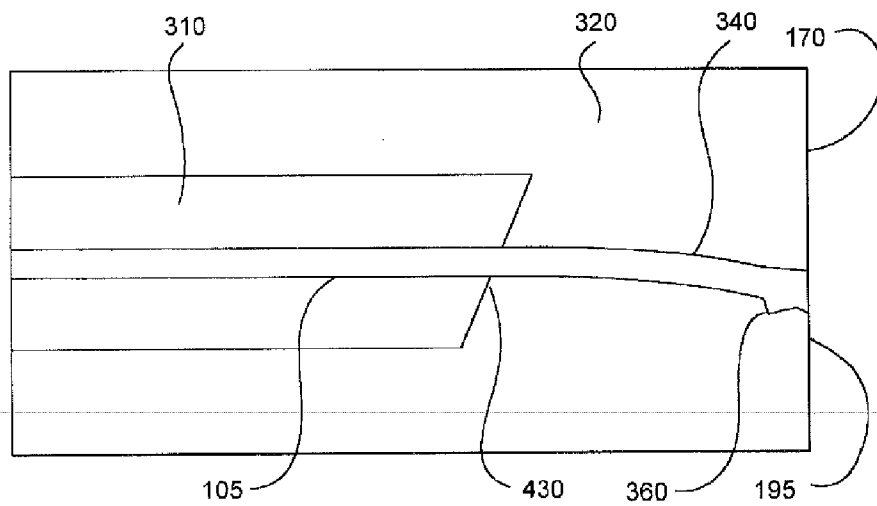


FIG. 3D

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**TUNABLE LASER SOURCE WITH
INTEGRATED OPTICAL AMPLIFIER**

This application is continuation-in-part and claims the benefit of priority of U.S. provisional application Ser. No. 60/152,072, filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. provisional application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614,377, 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. No. 09/614,674, Ser. No. 09/614,378, Ser. No. 09/614,376, Ser. No. 09/614,195, Ser. No. 09/614,665 and Ser. No. 09/614,224, which applications are fully incorporated by reference herein.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

2. Brief Description of the Related Art

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

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Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure.

The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. 1B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. 2A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. 2B is a cross-sectional view of the FIG. 2 assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. 2C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. 3A is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. 3B is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. 3C is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a flared waveguide.

FIG. 3D is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. 1A shows a schematic of an embodiment of the invention. In FIG. 1A, laser assembly 100, waveguide 105, amplifier gain section 110, front resonator mirror 120, laser

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gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190 and output facet 195 are shown.

In FIG. 1A, laser assembly 100 comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror 120, laser gain section 130, laser phase control section 140, and back mirror 150 form a SODBR-type laser 180 in epitaxial structure 170. The front and back mirrors define a laser cavity. Amplifier gain section 110 and a portion of waveguide 105 define optical amplifier 190.

As shown in FIG. 1A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure 170 with the laser. Epitaxial structure 170 is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. 1 are gain sections 110 and 130, phase control section 140 and mirrors 120 and 150. An example of an optically passive section is the portion of waveguide 105 proximal to output facet 195.

According to the invention, at least a portion of laser 180 and optical amplifier 190 share a common waveguide 105. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. 1A, amplifier 190 is external to the resonant cavity of laser 180 formed by mirrors 120 and 150. Moreover, amplifier gain section 110 is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGBDR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. 1A, optical amplifier 190 has an active section and a passive section. The active section, amplifier gain section 110, is substantially straight. The passive section of waveguide 105 is curved and intersects output facet 195 at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier 190 and laser 180.

FIG. 1B shows a longitudinal cross section of a laser assembly 100 of FIG. 1A. In FIG. 1B, laser assembly 100, waveguide 105, amplifier gain section 110, front resonator mirror 120, laser gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190, output facet 195, p type semiconductor layer 125, n-type semiconductor layer 115, mirror sampling period 135, offset quantum wells 145 and stop etch layer 155 are shown.

In FIG. 1B waveguide 105 is formed between p-type and n-type semiconductor layers 125 and 115, respectively. Mirrors 120 and 150 are formed by sample gratings etched in waveguide 105 with sampling period 135, as is well-understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive

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section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers 145 grown in a region offset from waveguide 105. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer 155. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly 100 (see FIG. 1) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. 2A illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. 2A, optically passive section 210, optically active section 220, bandgap-shifted quantum wells 230, active section quantum wells 240, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2A, different portions of waveguide 105 are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. 2B illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. 2B, optically passive section 210, optically active section 220, disordered wells 250, active section multiple quantum wells 260, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, different portions of waveguide 105, sections 210 and 220, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. 2C illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. 2B, optically passive section 210, optically active section 220, active, butt-joint interface 270, passive waveguide section 275, active waveguide section 285 and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, active waveguide section 285 and passive waveguide section 275 are separated by a distinct large gradient butt-joint interface 270 as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier 190 (see FIG. 1). In FIGS. 3A–3D optical amplifier 190, waveguide 105, epitaxial structure 170, output facet 195, active amplifier section 310, passive amplifier section 320, active-passive junction 330, curved waveguide portion 340, flared waveguide portions 350 and 355 and waveguide mode adapter 360 are shown.

In FIG. 3A, optical amplifier 190 has an active amplifier section 310 combined with a passive amplifier section 320, where the passive amplifier section includes curved

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waveguide portion 340. The curved waveguide portion intersects output facet 195 at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction 330 is preferably oblique to a centerline of waveguide 105 so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction 330 substantially normal to a centerline of the waveguide.

FIG. 3B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. 3B, the amplifier active section is segmented into two amplifier active sections 310 that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. 3C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion 350 increases the amplifier active volume as compared to the embodiment shown in FIG. 3A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section 355 to a narrow waveguide cross-section is positioned in the amplifier optically passive section 320 since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet 195. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion 340, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. 3C, active-passive junction 330 is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. 3D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet 195 so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly 100 (see FIG. 1) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

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What is claimed is:

1. A diode laser assembly, comprising:
substrate;

an epitaxial structure formed on the substrate;

a laser formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

an amplifier formed in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflection from an output facet.

2. The laser assembly of claim 1 wherein the common waveguide has non-uniform optical properties along its centerline.

3. The laser assembly of claim 1 wherein the common waveguide has non-uniform cross-sectional area along its centerline.

4. The laser assembly of claim 1 wherein the common waveguide has non-uniform curvature along its centerline.

5. The laser assembly of claim 1 wherein the common waveguide has non-uniform optical properties normal to its centerline.

6. The assembly of claim 1, wherein the amplifier includes at least one active region and at least one passive region.

7. The assembly of claim 6, wherein the waveguide extends through an active region and a passive region.

8. The assembly of claim 7, wherein a portion of the waveguide in the amplifier is curved.

9. The assembly of claim 7, wherein at least a portion of the waveguide in a passive region of the amplifier is curved.

10. The assembly of claim 7, wherein a portion of the waveguide in the amplifier is curved and the amplifier includes a flared waveguide section.

11. The assembly of claim 7, wherein an interface between the active region and the passive region is oblique to a centerline of the waveguide.

12. The assembly of claim 7, wherein an interface between the active region and the passive region is substantially normal to a centerline of the waveguide.

13. The assembly of claim 7, wherein an end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

14. The assembly of claim 6, wherein the waveguide includes a waveguide mode adapter.

15. The assembly of claim 6, wherein the first active region has a oblique distal face.

16. The assembly of claim 1, wherein the laser has a multi-active region gain medium.

17. The assembly of claim 1, wherein the epitaxial structure has areas of differing optical properties.

18. The assembly of claim 1, wherein the waveguide includes active section.

19. The assembly of claim 18, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

20. The assembly of claim 18, where the active section of the waveguide is positioned in the second active section of the amplifier.

21. The assembly of claim 1, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

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22. The assembly of claim 1, wherein the amplifier includes a plurality of independently controllable active regions.

23. The assembly of claim 22, wherein a first and a second active region are separated by a passive region.

24. The assembly of claim 23, wherein the first active region has an oblique distal face.

25. The assembly of claim 23, wherein the second active region has an oblique proximal face.

26. The assembly of claim 23, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

27. The assembly of claim 23, wherein the second active region has an oblique distal face.

28. The assembly of claim 27, wherein the proximal face and the distal face of the second region are parallel.

29. The assembly of claim 1, wherein a width of the laser output is independent of a width of the waveguide at an output of the amplifier.

30. The assembly of claim 1, wherein the laser includes a mode selection element.

31. The assembly of claim 30, wherein the mode selection element is a controllable phase shifting element.

32. The assembly of claim 1, wherein at least one of the first and second reflectors is tunable.

33. The assembly of claim 32, wherein at least one of the first and second reflectors is a distributed reflector.

34. The assembly of claim 32, wherein both of the first and second reflectors are distributed reflectors.

35. The assembly of claim 32, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

36. The assembly of claim 32, wherein each of the first and second reflectors is a distributed Bragg reflector.

37. The assembly of claim 32, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

38. The assembly of claim 32, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

39. The assembly of claim 32, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

40. The assembly of claim 32, wherein the laser includes an attenuator and at least one amplifier positioned outside of the laser.

41. The assembly of claim 32, wherein the laser includes a controllable amplifier positioned outside of the laser.

42. The assembly of claim 32, wherein the laser includes a controllable attenuator positioned outside of the laser.

43. The assembly of claim 1, wherein at least a portion of the waveguide is flared.

44. The assembly of claim 43, wherein a flared portion of the waveguide is in an active region.

45. The assembly of claim 43, wherein a flared portion of the waveguide is in a passive region.

46. The assembly of claim 1, wherein the optical signal is tunable within a range of at least 15 nm.

47. A diode laser assembly, comprising:

a first semiconductor layer in an epitaxial structure;

a second semiconductor layer formed in the epitaxial structure, the first and second semiconductor layers having different dopings;

a waveguide layer formed between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

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an amplifier formed in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned, the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

48. The assembly of claim 47, wherein a distal portion of the waveguide in the amplifier is curved.

49. The assembly of claim 47, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The assembly of claim 47, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity.

51. The assembly of claim 47, wherein at least a portion of the waveguide is flared.

52. The assembly of claim 47, wherein the waveguide includes an active section.

53. The assembly of claim 52, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

54. The assembly of claim 52, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

55. The assembly of claim 47, wherein the amplifier includes a first active region and a passive region.

56. The assembly of claim 55, wherein the amplifier includes a second active region.

57. The assembly of claim 55, wherein the first and second active regions are separated by a passive region.

58. The assembly of claim 57, wherein the first active region has an oblique distal face.

59. The assembly of claim 58, wherein the second active region has an oblique proximal face.

60. The assembly of claim 59, wherein the oblique distal face of the first active region is parallel to the oblique proximal face of the second active region.

61. The assembly of claim 59, wherein the second active region has an oblique distal face.

62. The assembly of claim 61, wherein the proximal face and the distal face of the second region are parallel.

63. The assembly of claim 55, wherein the waveguide extends through at least a portion of the amplifier.

64. The assembly of claim 55, wherein the first active region has an oblique distal face.

65. The assembly of claim 55, wherein the waveguide extends through the first active region and the passive region.

66. The assembly of claim 55, wherein the waveguide includes a mode adapter.

67. The assembly of claim 47, wherein at least one of the first and second reflectors is tunable.

68. The assembly of claim 67, wherein both of the first and second reflectors is a distributed reflector.

69. The assembly of claim 67, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

70. The assembly of claim 67, wherein each of the first and second reflectors is a distributed Bragg reflector.

71. The assembly of claim 67, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

72. The assembly of claim 67, wherein a maximum reflectivity of each of the first and second reflectors is tunable.

73. The assembly of claim 67, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

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74. The assembly of claim 67, wherein the laser includes a controllable amplifier positioned outside of the laser.

75. The assembly of claim 67, wherein the laser includes a controllable attenuator positioned outside of the laser.

76. The assembly of claim 67, wherein the laser includes an attenuator and at least one amplifier positioned outside of the resonant cavity.

77. The assembly of claim 67, wherein at least one of the first and second reflectors is a distributed reflector.

78. The assembly of claim 47, wherein the laser includes a mode selection element.

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79. The assembly of claim 78, wherein the mode selection element is a controllable phase shifting element.

80. The assembly of claim 47, wherein the optical signal is tunable within a range of at least 15 nm.

81. The assembly of claim 47, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

82. The assembly of claim 47, wherein the epitaxial structure has areas of differing optical properties.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,658,035 B1
DATED : December 2, 2003
INVENTOR(S) : Thomas Beck Mason, Gregory Fish and Larry Coldren

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,

Line 17, "reflection" should read -- reflections --.

Column 7,

Line 23, delete "the" (second occurrence).

Column 8,

Line 34, "au" should read -- an --.

Signed and Sealed this

Sixteenth Day of March, 2004

A handwritten signature in black ink, reading "Jon W. Dudas". The signature is written in a cursive style with a large, stylized "J" and "D".

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office

EXHIBIT 2



US006654400B1

(12) **United States Patent**
Mason et al.

(10) Patent No.: **US 6,654,400 B1**
(45) Date of Patent: **Nov. 25, 2003**

(54) **METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 302 days.

(21) Appl. No.: **09/614,224**

(22) Filed: **Jul. 12, 2000**

Related U.S. Application Data

- (63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,665, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000.
- (60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

- (51) Int. Cl.⁷ **H01S 5/026**
(52) U.S. Cl. **372/50; 372/20; 438/22**
(58) Field of Search **372/20, 50; 438/34, 438/22**

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(List continued on next page.)

Primary Examiner—Quyen Leung

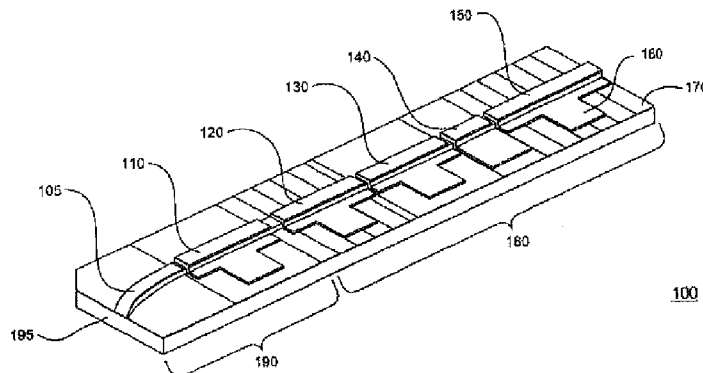
Assistant Examiner—Jeffrey Zahn

(74) Attorney, Agent, or Firm—Gates & Cooper LLP

(57) ABSTRACT

A method of making a diode laser assembly provides a substrate. An epitaxial structure is formed on the substrate. Different areas of the epitaxial structure have different optical properties. A laser, a modulator and a coupler are formed in the epitaxial structure.

76 Claims, 7 Drawing Sheets



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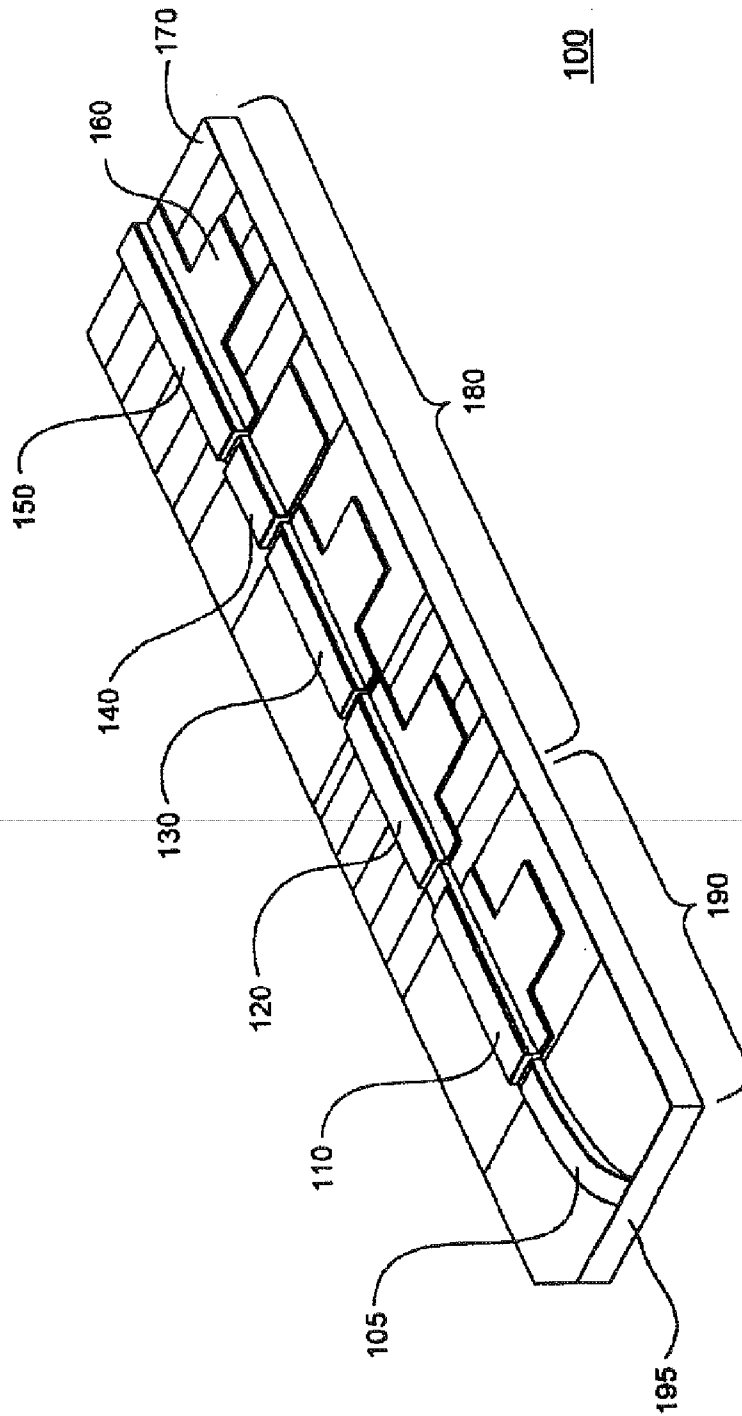


FIG. 1A

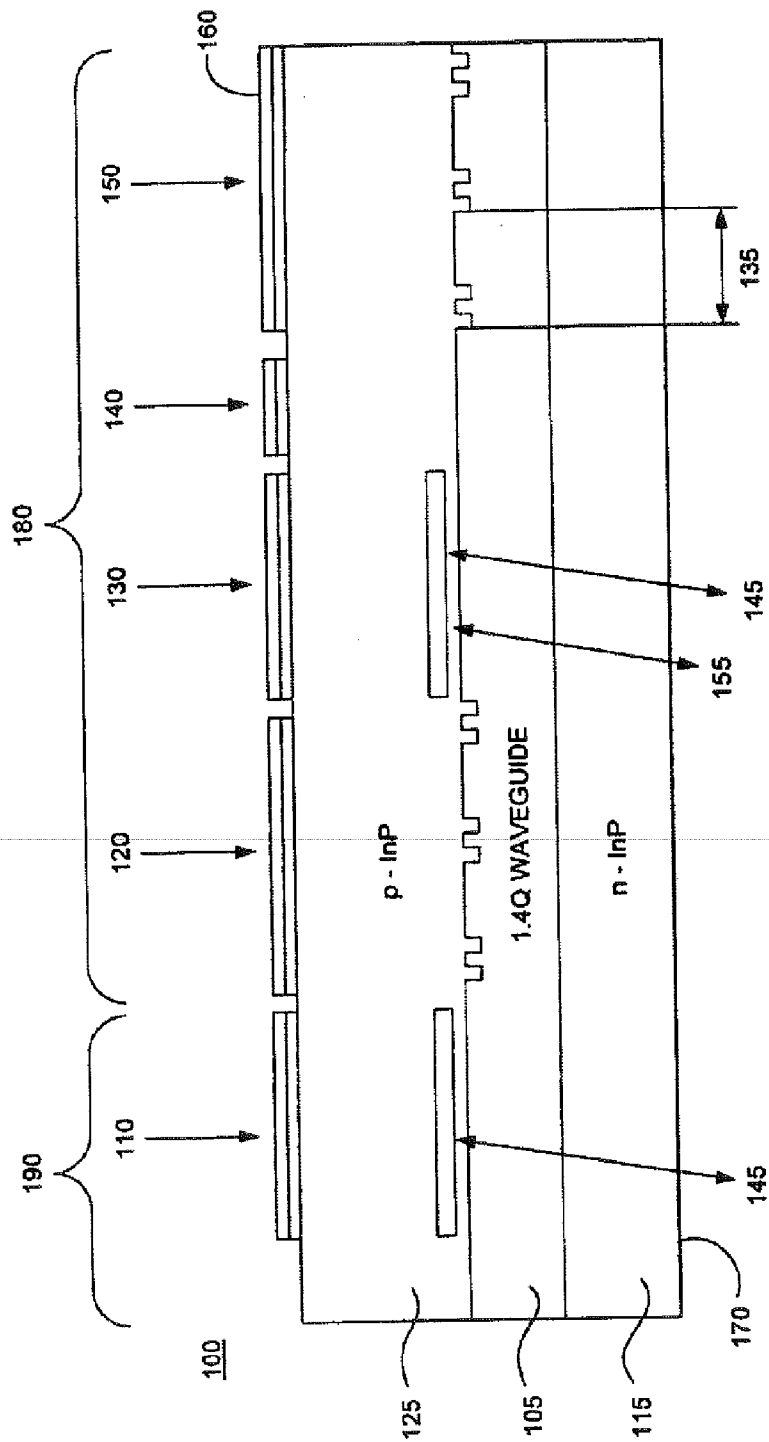


FIG. 1B

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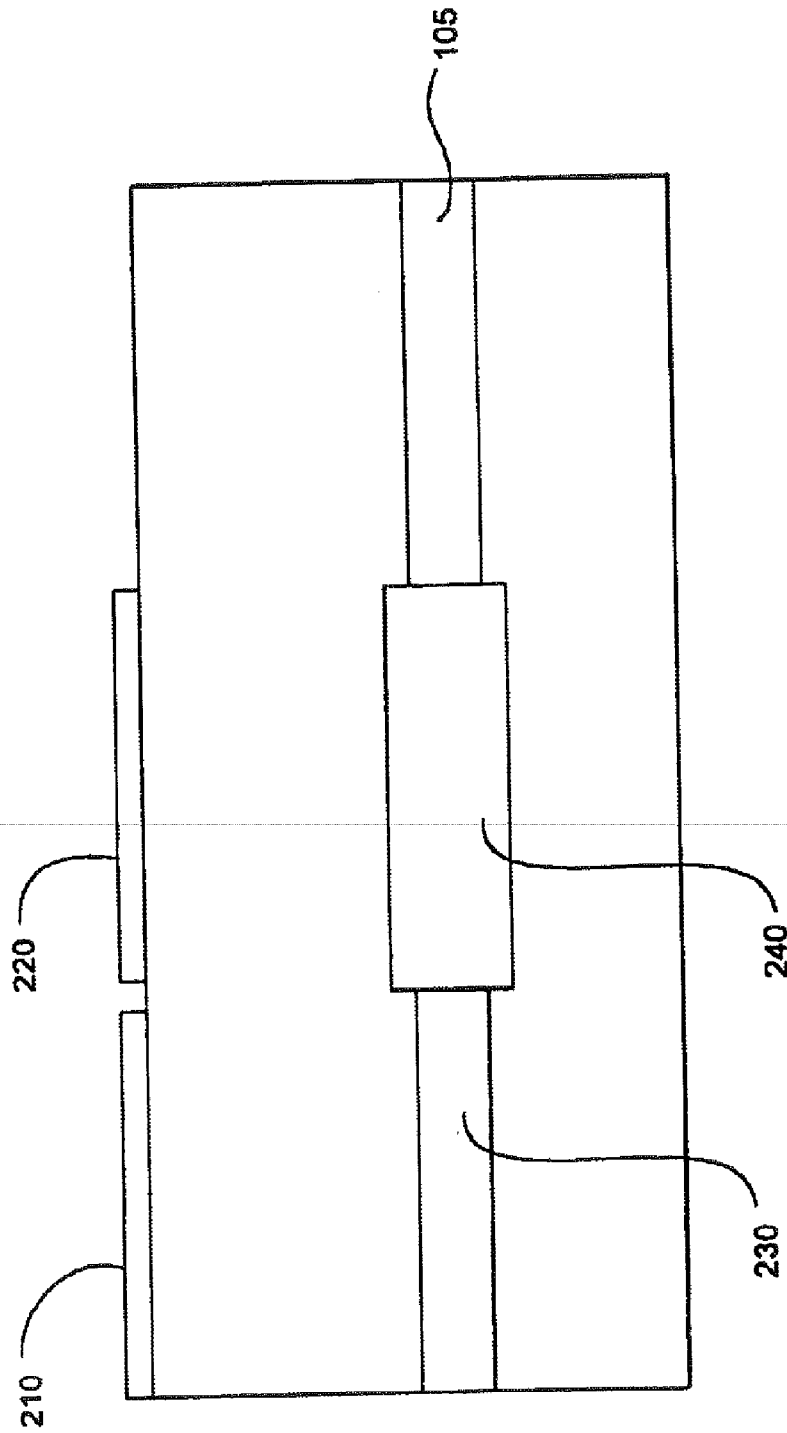


FIG. 2A

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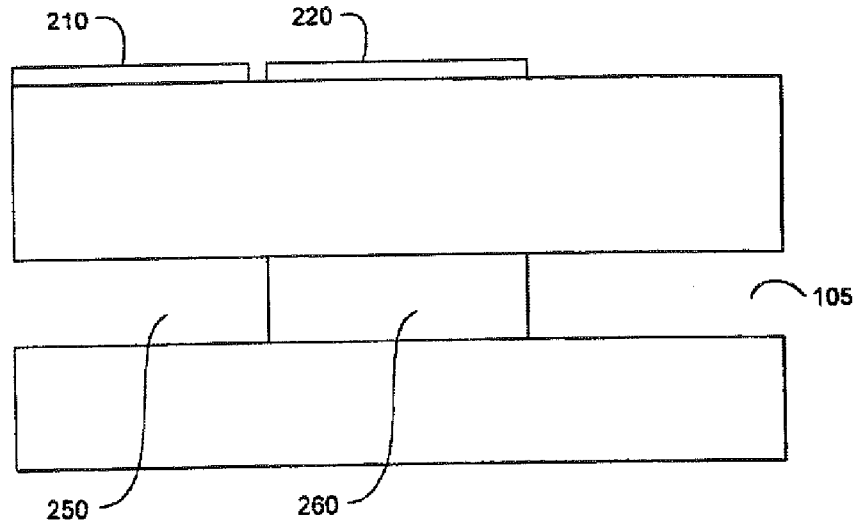


FIG. 2B

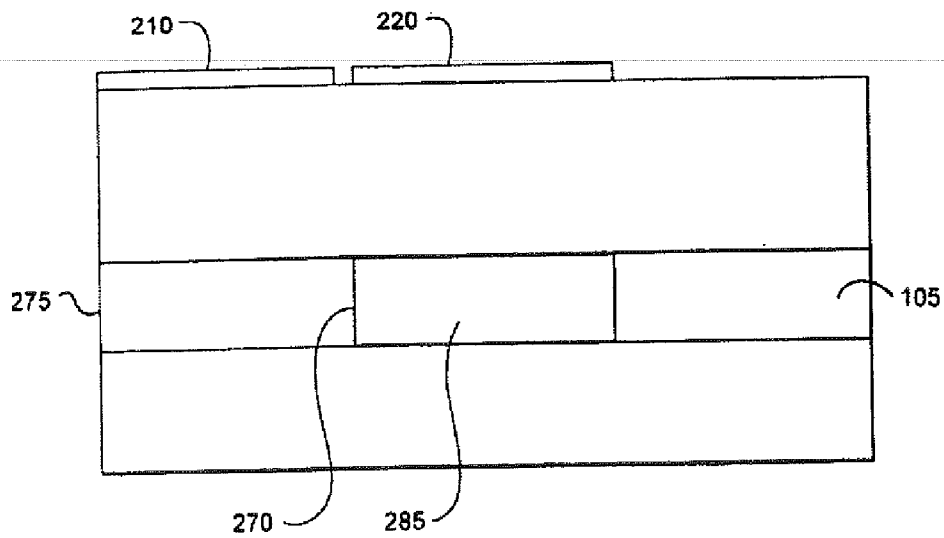


FIG. 2C

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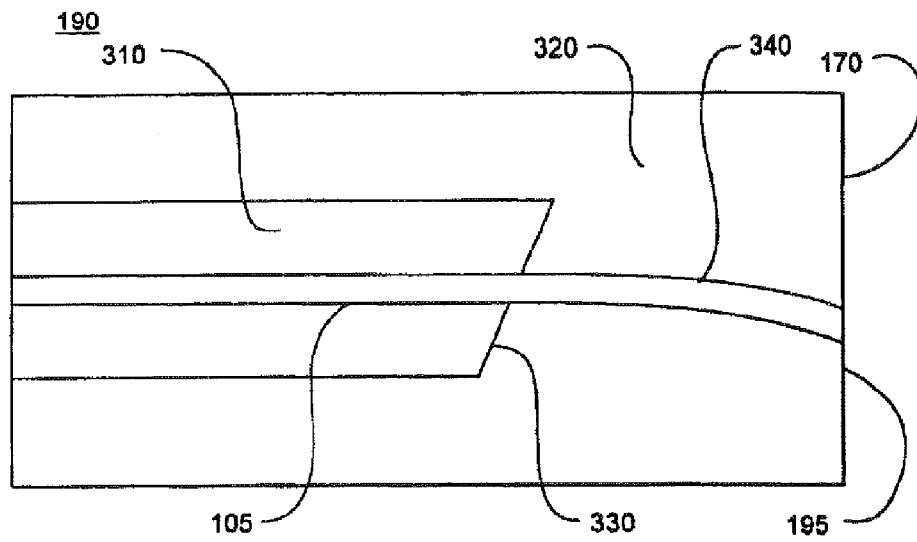


FIG. 3A

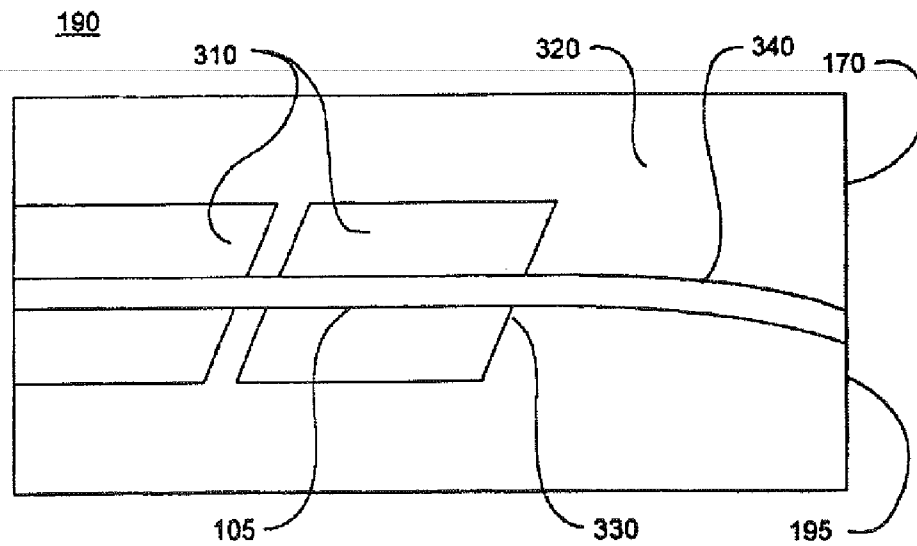


FIG. 3B

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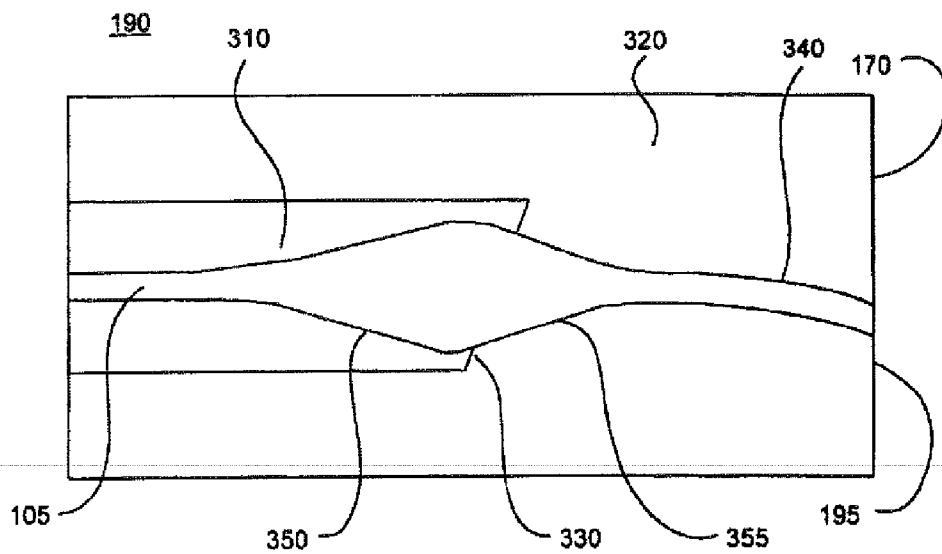


FIG. 3C

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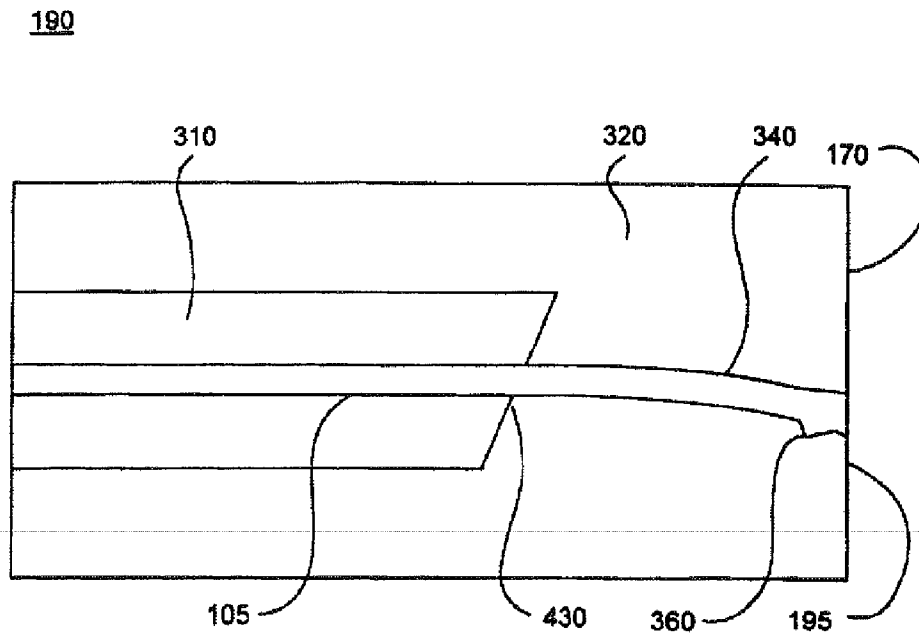


FIG. 3D

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METHOD OF MAKING A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Serial No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Serial No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614,377, now U.S. Pat. No. 6,580,739 09/614,895 (now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376, 09/614,195, now U.S. Pat. No. 6,574,259 09/614,375 and 09/614,665, filed on the same date Jul. 12, 2000 which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable

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solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are nonuniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. 1B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. 2A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. 2B is a cross-sectional view of the FIG. 2 assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. 2C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. 3A is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. 3B is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. 3C is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a flared waveguide.

FIG. 3D is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. 1A shows a schematic of an embodiment of the invention. In FIG. 1A, laser assembly 100, waveguide 105,

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amplifier gain section 110, front resonator mirror 120, laser gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190 and output facet 195 are shown.

In FIG. 1A, laser assembly 100 comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror 120, laser gain section 130, laser phase control section 140, and back mirror 150 form a SGDBR-type laser 180 in epitaxial structure 170. The front and back mirrors define a laser cavity. Amplifier gain section 110 and a portion of waveguide 105 define optical amplifier 190.

As shown in FIG. 1A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure 170 with the laser. Epitaxial structure 170 is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. 1 are gain sections 110 and 130, phase control section 140 and mirrors 120 and 150. An example of an optically passive section is the portion of waveguide 105 proximal to output facet 195.

According to the invention, at least a portion of laser 180 and optical amplifier 190 share a common waveguide 105. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. 1A, amplifier 190 is external to the resonant cavity of laser 180 formed by mirrors 120 and 150. Moreover, amplifier gain section 110 is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGDBR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. 1A, optical amplifier 190 has an active section and a passive section. The active section, amplifier gain section 110, is substantially straight. The passive section of waveguide 105 is curved and intersects output facet 195 at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier 190 and laser 180.

FIG. 1B shows a longitudinal cross section of a laser assembly 100 of FIG. 1A. In FIG. 1B, laser assembly 100, waveguide 105, amplifier gain section 110, front resonator mirror 120, laser gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190, output facet 195, p-type semiconductor layer 125, n-type semiconductor layer 115, mirror sampling period 135, offset quantum wells 145 and stop etch layer 155 are shown.

In FIG. 1B waveguide 105 is formed between p-type and n-type semiconductor layers 125 and 115, respectively. Mirrors 120 and 150 are formed by sample gratings etched in waveguide 105 with sampling period 135, as is well understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive

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section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers 145 grown in a region offset from waveguide 105. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer 155. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly 100 (see FIG. 1) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. 2A illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. 2A, optically passive section 210, optically active section 220, bandgap-shifted quantum wells 230, active section quantum wells 240, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2A, different portions of waveguide 105 are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. 2B illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. 2B, optically passive section 210, optically active section 220, disordered wells 250, active section multiple quantum wells 260, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, different portions of waveguide 105, sections 210 and 220, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. 2C illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. 2B, optically passive section 210, optically active section 220, active, butt-joint interface 270, passive waveguide section 275, active waveguide section 285 and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, active waveguide section 285 and passive waveguide section 275 are separated by a distinct large gradient butt-joint interface 270 as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier 190 (see FIG. 1). In FIGS. 3A–3D optical amplifier 190, waveguide 105, epitaxial structure 170, output facet 195, active amplifier section 310, passive amplifier section 320, active-passive junction 330, curved waveguide portion 340, flared waveguide portions 350 and 355 and waveguide mode adapter 360 are shown.

In FIG. 3A, optical amplifier 190 has an active amplifier section 310 combined with a passive amplifier section 320, where the passive amplifier section includes curved

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waveguide portion 340. The curved waveguide portion intersects output facet 195 at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction 330 is preferably oblique to a centerline of waveguide 105 so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction 330 substantially normal to a centerline of the waveguide.

FIG. 3B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. 3B, the amplifier active section is segmented into two amplifier active sections 310 that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. 3C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion 350 increases the amplifier active volume as compared to the embodiment shown in FIG. 3A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section 355 to a narrow waveguide cross-section is positioned in the amplifier optically passive section 320 since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet 195. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion 340, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. 3C, active-passive junction 330 is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. 3D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet 195 so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly 100 (see FIG. 1) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of making a diode laser assembly, comprising:

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providing a substrate;

forming an epitaxial structure on the substrate, the epitaxial structure having optically active and optically inactive areas;

forming a laser in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom; and

forming an amplifier in the epitaxial structure, at least a portion of the laser and amplifier sharing a common waveguide, the tunable laser output being coupled to the amplifier along the common waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

2. The method of claim 1, wherein the optically active areas of the epitaxial structure are formed using off-set quantum wells.

3. The method of claim 1, wherein the optically inactive areas are formed by a selective area growth.

4. The method of claim 1, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

5. The method of claim 1, wherein the optically inactive areas are formed by selective area disordering.

6. The method of claim 1, wherein the optically inactive areas are formed by butt joint regrowth.

7. The method of claim 1, wherein the optically inactive areas are formed with multiple quantum well layers grown on top of the waveguide layer.

8. The method of claim 1, further comprising:

forming areas of different bandgaps in the epitaxial structure.

9. The method of claim 1, further comprising:

bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create the gain section of the laser.

10. The method of claim 9, further comprising:

annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

11. The method of claim 9, wherein the ions have an energy no greater than about 200 eV.

12. The method of claim 1, wherein the amplifier includes a first active region and a passive region.

13. The method of claim 12, wherein the waveguide extends through at least a portion of the amplifier.

14. The method of claim 13, wherein the waveguide extends through the first active region and the passive region.

15. The method of claim 14, wherein a distal portion of the waveguide in the amplifier is curved.

16. The method of claim 14, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

17. The method of claim 14, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

18. The method of claim 12, wherein the first active region has a tapered distal face.

19. The method of claim 12, wherein the amplifier includes a second active region.

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20. The method of claim 19, wherein the waveguide includes an active section.

21. The method of claim 20, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

22. The method of claim 20, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

23. The method of claim 19, wherein the first and second active regions are separated by a passive region.

24. The method of claim 23, wherein the first active region has a tapered distal face.

25. The method of claim 24, wherein the second active region has a tapered proximal face.

26. The method of claim 25, wherein the second active region has a tapered distal face.

27. The method of claim 26, wherein the proximal face and the distal face of the second region are parallel.

28. The method of claim 25, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

29. The method of claim 1, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

30. The method of claim 29, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

31. The method of claim 30, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

32. The method of claim 1, wherein at least a portion of the waveguide is non-parallel to an axis of the laser's cavity.

33. The method of claim 1, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

34. The method of claim 1, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier.

35. The method of claim 1, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that carries the light away from the output facet.

36. The method of claim 35, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

37. The method of claim 1, wherein the optical signal is tunable within a range of at least 15 nm.

38. The method of claim 1, wherein at least a portion of the waveguide is tapered.

39. A method of making a diode assembly, comprising:

providing a substrate;
forming a first semiconductor layer and a second semiconductor layer in an epitaxial structure having optically active and optically inactive areas, the first and second semiconductor layers having different dopings;
and

forming a first waveguide layer between the first and second semiconductor layers, the first waveguide layer including a waveguide, a first reflector and a second reflector;

forming an optically active medium disposed between the first and second reflectors, the first and second reflectors defining a laser cavity and producing a tunable laser output; and

forming an amplifier in the epitaxial structure, wherein the laser cavity and the amplifier are optically aligned,

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the tunable laser output being coupled into the amplifier along the waveguide, and the amplifier generating an optical signal in response to the coupled tunable laser output, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet.

40. The method of claim 39, further comprising: forming areas of different bandgaps in the epitaxial structure.

41. The method of claim 39, further comprising: bombarding at least a portion of the epitaxial structure with ions; and

tailoring a bandgap of at least a portion of the epitaxial structure to create a gain medium of the laser.

42. The method of claim 41, further comprising: annealing at least a portion of the epitaxial structure to diffuse impurities and vacancies in a selected region of the epitaxial structure to determine the region's optical properties.

43. The method of claim 41, wherein the ions have an energy no greater than about 200 eV.

44. The method of claim 39, wherein the amplifier includes a first active region and a passive region.

45. The method of claim 44, wherein the waveguide layer includes a waveguide that extends through at least a portion of the amplifier.

46. The method of claim 45, wherein the waveguide extends through the first active region and the passive region.

47. The method of claim 46, wherein a distal portion of the waveguide in the amplifier is curved.

48. The method of claim 46, wherein a distal portion of the waveguide in the amplifier is curved and the amplifier includes a tapered section.

49. The method of claim 46, wherein a distal end of the waveguide in the amplifier terminates at an oblique angle to an output facet.

50. The method of claim 45, wherein at least a portion of the waveguide is tapered.

51. The method of claim 44, wherein the amplifier includes a second active region.

52. The method of claim 51, wherein the waveguide includes an active section.

53. The method of claim 52, wherein the active section of the waveguide is positioned in the second active section of the amplifier.

54. The method of claim 52, wherein the active section of the waveguide is positioned in the first active section of the amplifier.

55. The method of claim 51, wherein the first and second active regions are separated by a passive region.

56. The method of claim 55, wherein the first active region has a tapered distal face.

57. The method of claim 56, wherein the second active region has a tapered proximal face.

58. The method of claim 57, wherein the second active region has a tapered distal face.

59. The method of claim 58, wherein the proximal face and the distal face of the second region are parallel.

60. The method of claim 57, wherein the tapered distal face of the first active region is parallel to the tapered proximal face of the second active region.

61. The method of claim 44, wherein the first active region has a tapered distal face.

62. The method of claim 39, wherein at least one of the first and second reflectors is a distributed Bragg reflector.

63. The method of claim 62, wherein a maximum reflectivity of at least one of the first and second reflectors is tunable.

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64. The method of claim 63, wherein the maximum reflectivities of each of the first and second reflectors are tunable relative to each other.

65. The method of claim 39, wherein at least a portion of the waveguide is non-parallel to an axis of the laser cavity. 5

66. The method of claim 39, wherein a width of the tunable laser output is independent of a width of the waveguide at an output of the amplifier.

67. The method of claim 39, wherein at least a portion of the waveguide is flared-out in an active section of the amplifier and flared-in in a passive section of the amplifier. 10

68. The method of claim 39, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet so that it is more closely matched to the mode in an optical fiber that carries the light away from the output facet. 15

69. The method of claim 68, wherein the waveguide mode adapter includes a section of passive waveguide and the waveguide's cross section is varied to expand the waveguide's optical mode in an adiabatic manner.

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70. The method of claim 39, wherein the optical signal is tunable within a range of at least 15 nm.

71. The method of claim 39, wherein the optically inactive areas are formed with multiple quantum well layers grow on top of the waveguide layer.

72. The method of claim 39, wherein the optically active areas in the epitaxial structure are formed using off-set quantum wells.

73. The method of claim 39, wherein the optically inactive areas in the epitaxial structure are formed by a selective area growth.

74. The method of claim 39, wherein the optically inactive areas are formed by a selective area growth using a dielectric mask.

75. The method of claim 39, wherein the optically inactive areas are formed by selective area disordering.

76. The method of claim 39, wherein the optically inactive areas are formed by butt joint regrowth.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,654,400 B1
DATED : November 25, 2003
INVENTOR(S) : Thomas Beck Mason, Gregory Fish and Larry Coldren

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It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,

Lines 2 and 3, "editorial" should read -- epitaxial --.

Line 63, "in" should read -- an --.

Signed and Sealed this

Sixteenth Day of March, 2004

A handwritten signature in black ink, appearing to read "Jon W. Dudas", is written over a horizontal line.

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office

EXHIBIT 3



US006687278B1

(12) **United States Patent**
Mason et al.

(10) **Patent No.:** US 6,687,278 B1
(45) **Date of Patent:** Feb. 3, 2004

(54) **METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER**

(75) Inventors: **Thomas Beck Mason**, Middletown, NJ (US); **Gregory Fish**, Santa Barbara, CA (US); **Larry Coldren**, Santa Barbara, CA (US)

(73) Assignee: **Agility Communications, Inc.**, Goleta, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 211 days.

(21) Appl. No.: 09/614,665

(22) Filed: Jul. 12, 2000

Related U.S. Application Data

- (63) Continuation-in-part of application No. 09/614,377, filed on Jul. 12, 2000, now Pat. No. 6,580,739, and a continuation-in-part of application No. 09/614,895, filed on Jul. 12, 2000, now Pat. No. 6,349,106, and a continuation-in-part of application No. 09/614,378, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,376, filed on Jul. 12, 2000, now Pat. No. 6,614,819, and a continuation-in-part of application No. 09/614,674, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,195, filed on Jul. 12, 2000, now Pat. No. 6,574,259, and a continuation-in-part of application No. 09/614,375, filed on Jul. 12, 2000, and a continuation-in-part of application No. 09/614,224, filed on Jul. 12, 2000.
- (60) Provisional application No. 60/152,072, filed on Sep. 2, 1999, provisional application No. 60/152,049, filed on Sep. 2, 1999, and provisional application No. 60/152,038, filed on Sep. 2, 1999.

(51) Int. Cl.⁷ H01S 5/026

(52) U.S. Cl. 372/50; 372/20; 438/22

(58) Field of Search 372/50, 20; 438/22

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Primary Examiner—Quyen Leung

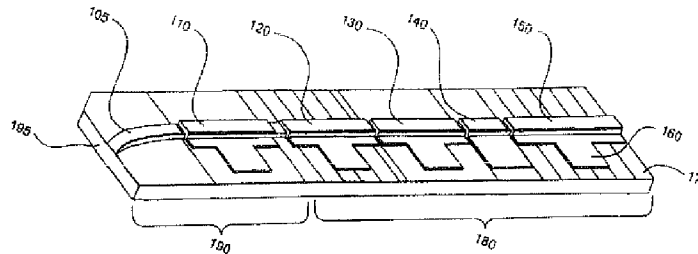
Assistant Examiner—Jeffrey Zahn

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(57) **ABSTRACT**

A method of generating an optical signal provides a diode laser assembly including an epitaxial structure formed on a substrate. A laser and an amplifier are formed in the epitaxial structure. At least a portion of the laser and amplifier share a common waveguide. A tunable laser output is produced from the laser. The laser output is coupled into the amplifier along the common waveguide. An optical signal is generated from the amplifier.

26 Claims, 7 Drawing Sheets



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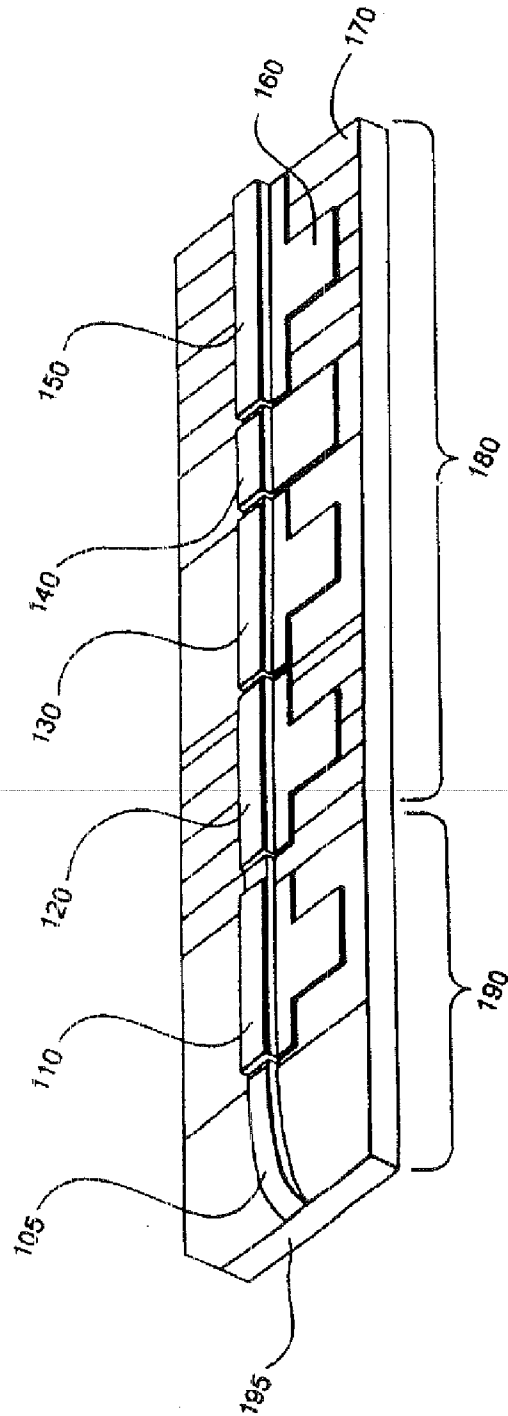


FIG. 1A

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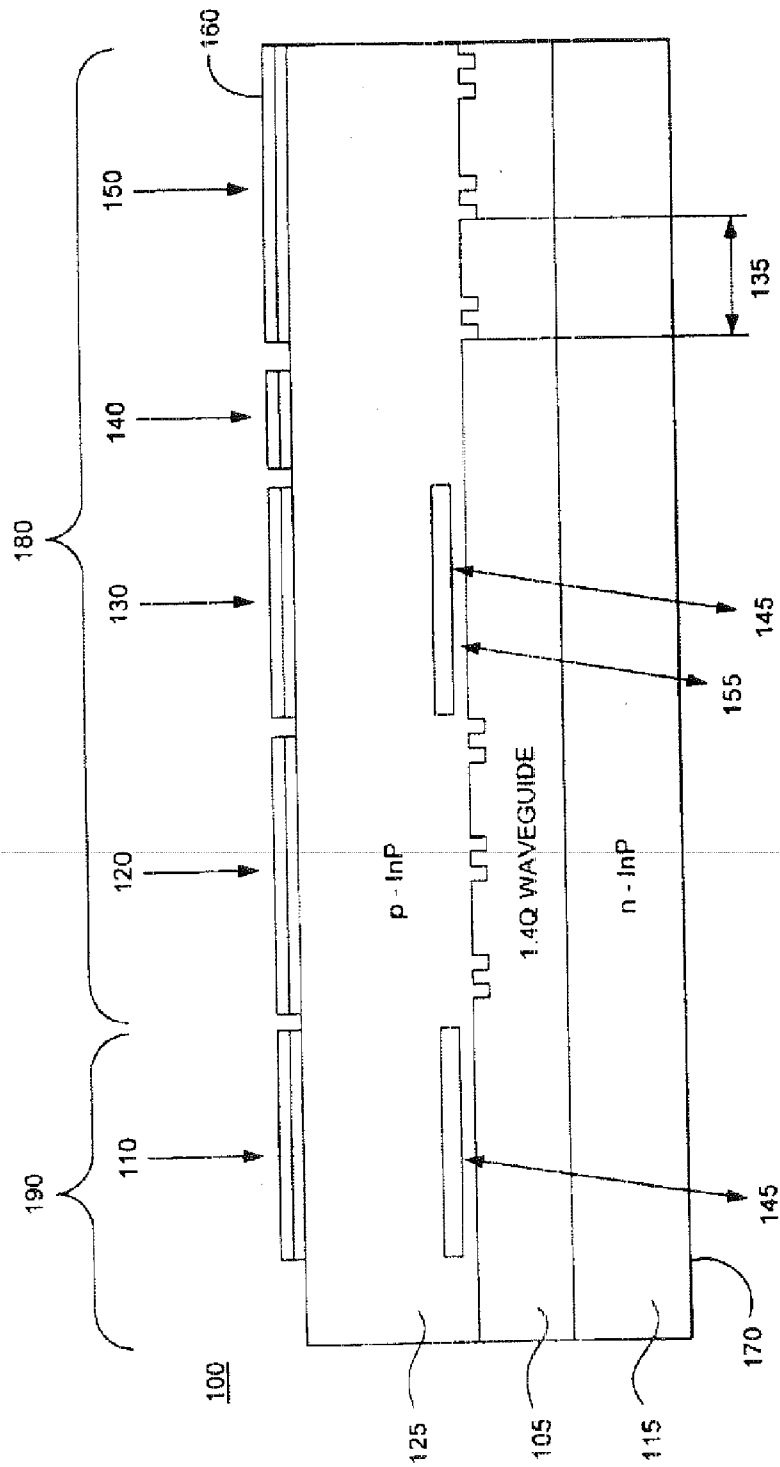


FIG. 1B

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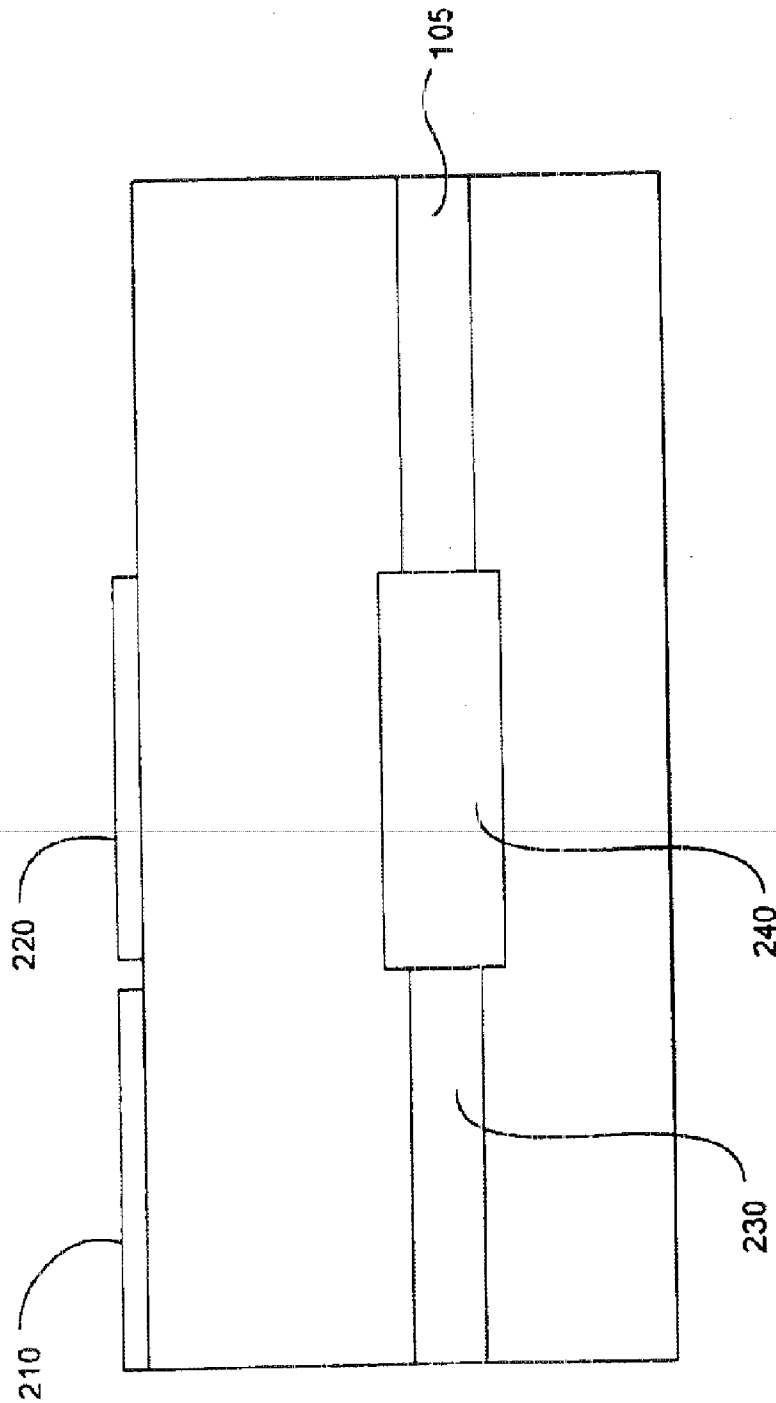


FIG. 2A

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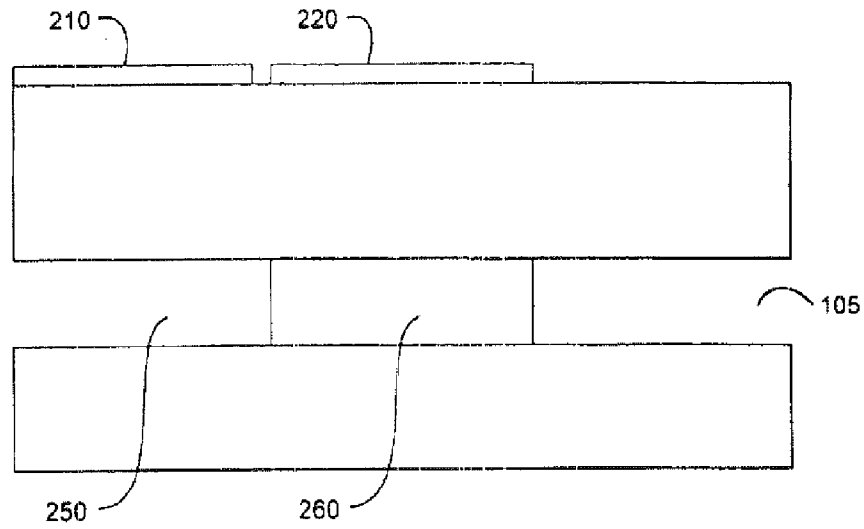


FIG. 2B

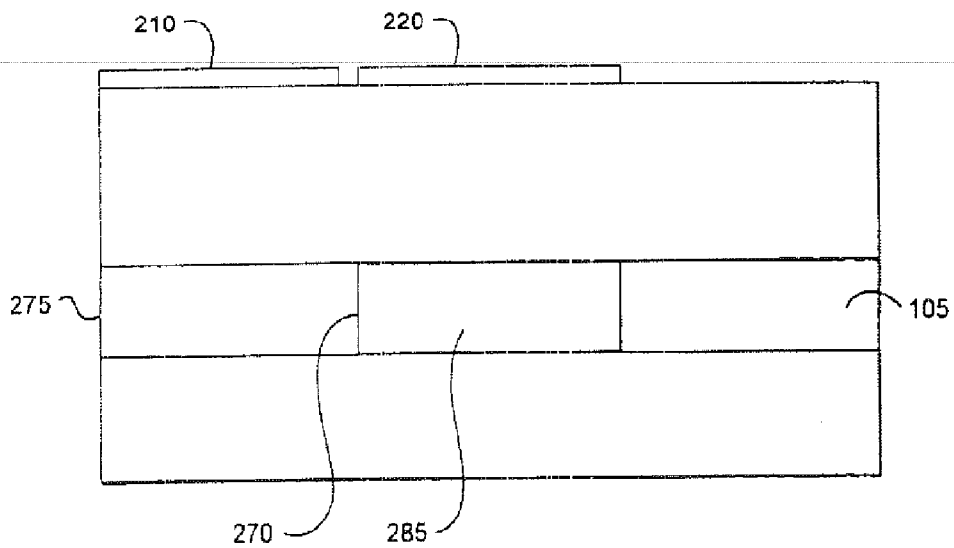


FIG. 2C

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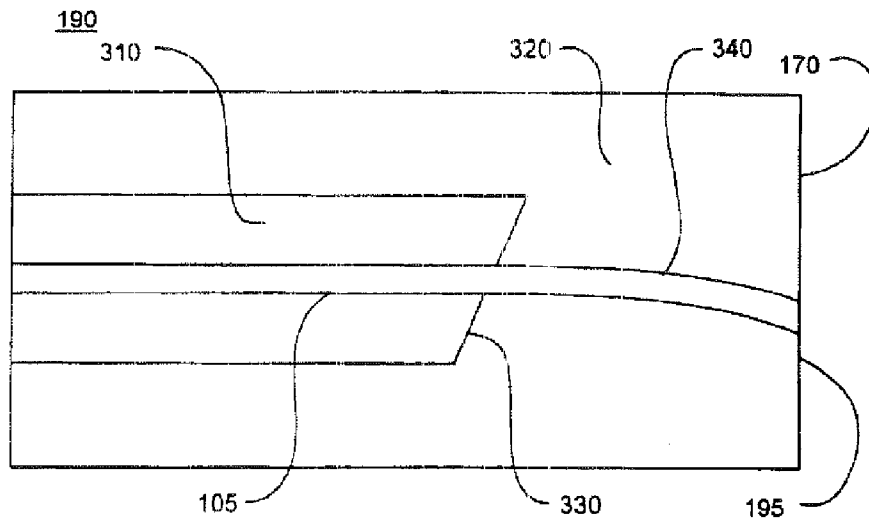


FIG. 3A

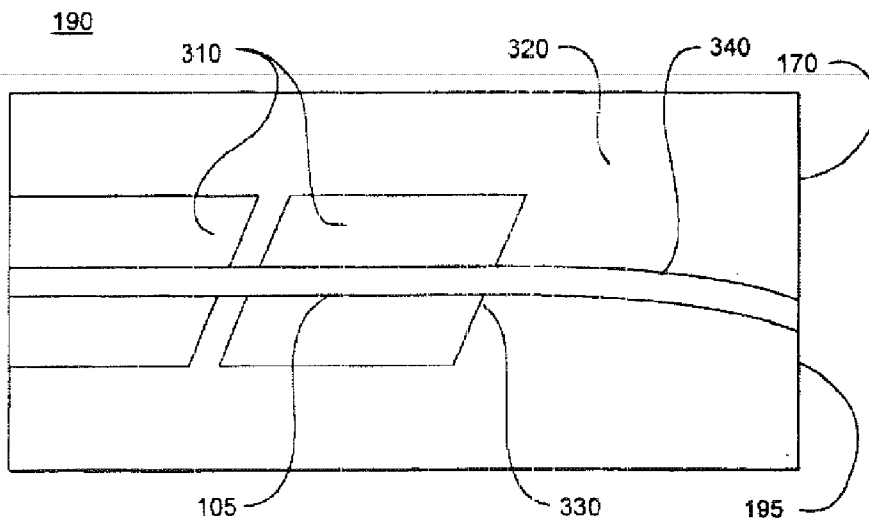


FIG. 3B

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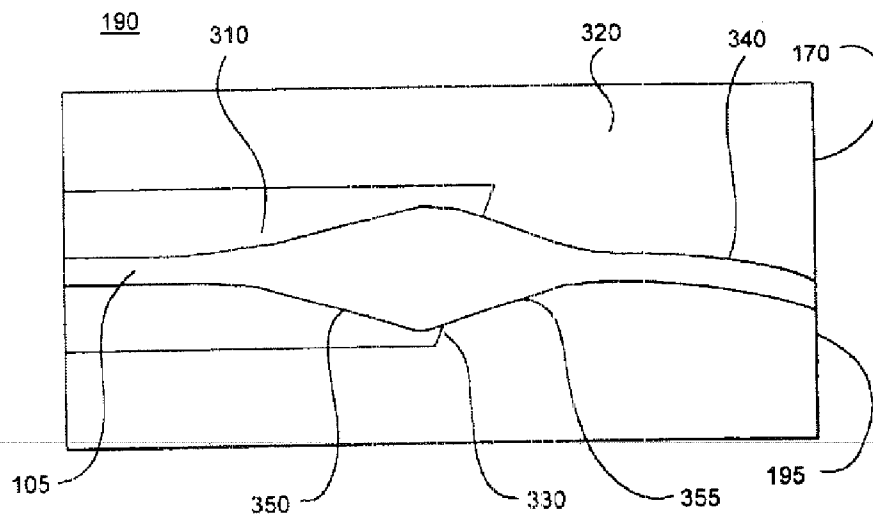


FIG. 3C

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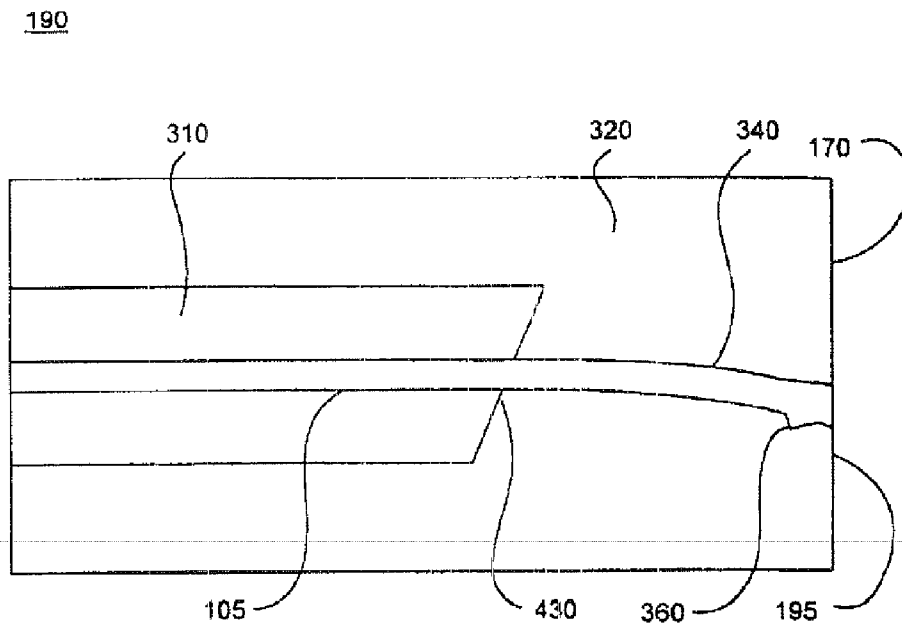


FIG. 3D

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METHOD OF GENERATING AN OPTICAL SIGNAL WITH A TUNABLE LASER SOURCE WITH INTEGRATED OPTICAL AMPLIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part and claims the benefit of priority of U.S. Provisional Application Ser. No. 60/152,072, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,049, filed Sep. 2, 1999, U.S. Provisional Application Ser. No. 60/152,038, filed Sep. 2, 1999, which applications are fully incorporated by reference herein. This application is also a continuation-in-part of U.S. Ser. Nos. 09/614,377 now U.S. Pat. No. 6,580,739, **09/614,895**(now U.S. Pat. No. 6,349,106, issued Feb. 19, 2002), Ser. Nos. 09/614,674, 09/614,378, 09/614,376 now U.S. Pat. No. 6,614,819, **09/614,195**now U.S. Pat. No. 6,574,259, **09/614,375**and 09/614,224, filed on the same date as this application, which applications are fully incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates generally to laser assemblies, and more particularly to a widely tunable laser assembly with an integrated optical amplifier.

BRIEF DESCRIPTION OF THE RELATED ART

Thin fibers of optical materials transmit light across a very broad frequency bandwidth and therefore communications data from a light source may be transmitted over such fibers over broad frequency ranges. At any particular frequency, a laser source must have high output power, narrow laser linewidth and good transmission performance through great distances of optical fiber.

In higher bandwidth communications systems, where many frequencies of laser light are transmitted along a fiber, there may be one or several laser sources. While a tunable laser source would be preferred, higher data capacity systems presently use multiple laser sources operating on different frequency channels to cover the wide fiber transmission bandwidth. This is the case since appropriate laser sources are presently incapable of rapid, electronic frequency tuning without attendant deterioration of other significant figures-of-merit.

For example, at a fixed frequency, sampled grating distributed Bragg reflector (SGDBR) lasers have the high output power, narrow laser linewidth and good transmission performance necessary for an optical data network. While some SGDBR lasers can be rapidly tuned over more than 100 different transmission channels, two problems nevertheless prevent these devices from being employed in fiber optic communication systems. The most significant problem is the significant absorption of the mirror material. The resulting large cavity losses act to make the laser output power insufficient for the requirements of a present-day communications system. A second problem is that the output power and frequency tuning are dependent on each other. This coupling results in inadequate controllability for a present-day communications system.

What is needed, instead, is a device with a combination of sufficiently high output power for a high-bandwidth optical communications network and with frequency tuning controllability substantially independent of output power controllability.

SUMMARY

Accordingly, an object of the present invention is to provide an integrated laser assembly that includes a tunable

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solid state laser and optical amplifier where all of the elements are fabricated in a common epitaxial layer structure.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable solid state laser and optical amplifier with an output mode conditioned for transmission in an optical fiber.

Another object of the present invention is to provide an integrated laser assembly that includes a tunable laser and optical amplifier reducing optical feedback from the amplifier to the laser.

A further object of the present invention is to provide a tunable, integrated laser assembly where laser frequency control and output power control are substantially independent.

These and other objects of the present invention are achieved in a laser assembly that includes an epitaxial structure formed on a substrate. A tunable laser resonator and a separately controllable optical amplifier are formed in the common epitaxial structure. The amplifier is positioned outside of the laser resonator cavity to receive and adjust an output received from the laser, however, at least a portion of the laser and amplifier share a common waveguide.

In different embodiments of the present invention, properties of the common waveguide such as optical properties, or centerline curvature or cross-sectional are non-uniform along the waveguide centerline or non-uniform across a normal to the centerline.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1A is a block diagram of a laser assembly that illustrates different functional elements of a laser assembly.

FIG. 1B is a cross-sectional view of one embodiment of a widely tunable laser assembly of the present invention and the integration of materials with differing optical properties by an offset quantum well technique.

FIG. 2A is a cross-sectional view of one embodiment of an amplifier illustrating several layer structures and the integration of two materials with differing optical properties by a selected area growth technique.

FIG. 2B is a cross-sectional view of the FIG. 2 assembly illustrating one embodiment for the integration of materials with differing optical properties by a disordered well technique.

FIG. 2C is a cross-sectional view of one embodiment of an amplifier illustrating one embodiment for the integration of several different band gap materials by a butt joint regrowth technique.

FIG. 3A is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where a portion of the waveguide is curved and an interface between an active and a passive section is oblique.

FIG. 3B is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a plurality of gain sections.

FIG. 3C is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a flared waveguide.

FIG. 3D is a cross-sectional view of one embodiment of the FIG. 1 optical amplifier element where the amplifier includes a waveguide mode adapter.

DETAILED DESCRIPTION

FIG. 1A shows a schematic of an embodiment of the invention. In FIG. 1A, laser assembly 100, waveguide 105,

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amplifier gain section 110, front resonator mirror 120, laser gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190 and output facet 195 are shown.

In FIG. 1A, laser assembly 100 comprises an integration of a laser and an optical amplifier, with the optical amplifier located external to the laser cavity. Front resonator mirror 120, laser gain section 130, laser phase control section 140, and back mirror 150 form a SGDBR-type laser 180 in epitaxial structure 170. The front and back mirrors define a laser cavity. Amplifier gain section 110 and a portion of waveguide 105 define optical amplifier 190.

As shown in FIG. 1A, despite being external to the laser cavity, the optical amplifier shares a common epitaxial structure 170 with the laser. Epitaxial structure 170 is formed on a substrate (not shown) by processes well-known in the art of semiconductor fabrication. By tailoring optical properties (such as band gap) of different portions of the epitaxial structure, both optically active and optically passive sections can be fabricated in a common structure. Examples of optically active sections of the embodiment shown in FIG. 1 are gain sections 110 and 130, phase control section 140 and mirrors 120 and 150. An example of an optically passive section is the portion of waveguide 105 proximal to output facet 195.

According to the invention, at least a portion of laser 180 and optical amplifier 190 share a common waveguide 105. Different portions of the common waveguide may extend through optically active or passive regions. A common waveguide for the laser and optical amplifier enables the output from the laser to be directly coupled into the amplifier.

In the embodiment of FIG. 1A, amplifier 190 is external to the resonant cavity of laser 180 formed by mirrors 120 and 150. Moreover, amplifier gain section 110 is separately controllable from the laser and is adjustable to increase or decrease the light intensity and output power. The SGDBR laser elements may be controlled separately from the amplifier to tune the laser frequency and otherwise control the input to the optical amplifier. By this arrangement of elements, power amplification and tuning functions are substantially uncoupled.

In the embodiment of FIG. 1A, optical amplifier 190 has an active section and a passive section. The active section, amplifier gain section 110, is substantially straight. The passive section of waveguide 105 is curved and intersects output facet 195 at an oblique angle. Both waveguide curvature and the oblique intersection with the output facet act to prevent reflections at the output facet from coupling back into the optical amplifier 190 and laser 180.

FIG. 1B shows a longitudinal cross section of a laser assembly 100 of FIG. 1A. In FIG. 1B, laser assembly 100, waveguide 105, amplifier gain section 110, front resonator mirror 120, laser gain section 130, laser phase control section 140, back mirror 150 and electrical contact 160, epitaxial structure 170, laser 180, optical amplifier 190, output facet 195, p type semiconductor layer 125, n-type semiconductor layer 115, mirror sampling period 135, offset quantum wells 145 and stop etch layer 155 are shown.

In FIG. 1B waveguide 105 is formed between p-type and n-type semiconductor layers 125 and 115, respectively. Mirrors 120 and 150 are formed by sample gratings etched in waveguide 105 with sampling period 135, as is well-understood in the art.

FIG. 1B illustrates the structure resulting from an offset quantum well technique for optically active and passive

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section formation. According to the offset quantum well technique, the optically active sections have multiple quantum well layers 145 grown in a region offset from waveguide 105. The multiple quantum well layers are separated from the waveguide by a thin stop etch layer 155. Removal of quantum wells, by etching for example, forms optically passive sections.

FIGS. 2A–2C illustrate cross-sectional structures over a portion of laser assembly 100 (see FIG. 1) resulting from different techniques for forming optically active and passive sections and their junctions. FIG. 2A illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area regrowth technique. The selected area regrowth technique uses a dielectric mask to selectively control the growth rate and composition over different areas of the epitaxial structure. Thus, the material's bandgap can be shifted in certain sections making the material in that section passive or non-absorbing at desired wavelengths. In FIG. 2A, optically passive section 210, optically active section 220, bandgap-shifted quantum wells 230, active section quantum wells 240, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2A, different portions of waveguide 105 are optically active or passive due to bandgap-shifting of the quantum wells within the waveguide.

FIG. 2B illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a selected area disordering technique for forming optically active and passive sections. The selected area disordering technique uses a dielectric cap or ion implantation to introduce vacancies which can be diffused through an active region to disorder the quantum wells by intermixing them. This disordering shifts quantum well bandgaps, creating optically passive waveguide sections.

In FIG. 2B, optically passive section 210, optically active section 220, disordered wells 250, active section multiple quantum wells 260, and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, different portions of waveguide 105, sections 210 and 220, are optically active or passive due to the organization of the quantum wells within the waveguide material.

FIG. 2C illustrates a cross-sectional structure over a portion of laser assembly 100 (see FIG. 1) resulting from a butt joint regrowth technique for forming optically active and passive sections. According to the butt joint regrowth technique, the entire waveguide is etched away in optically passive sections and an optically passive waveguide is grown again. The newly grown portion of the waveguide is butted up against the active waveguide. In FIG. 2B, optically passive section 210, optically active section 220, active, butt-joint interface 270, passive waveguide section 275, active waveguide section 285 and waveguide 105 (see FIGS. 1A–1B) are shown. In FIG. 2B, active waveguide section 285 and passive waveguide section 275 are separated by a distinct large gradient butt-joint interface 270 as a result of the etch removal process.

FIGS. 3A–3D are plan views, illustrating different embodiments of optical amplifier 190 (see FIG. 1). In FIGS. 3A–3D optical amplifier 190, waveguide 105, epitaxial structure 170, output facet 195, active amplifier section 310, passive amplifier section 320, active-passive junction 330, curved waveguide portion 340, flared waveguide portions 350 and 355 and waveguide mode adapter 360 are shown.

In FIG. 3A, optical amplifier 190 has an active amplifier section 310 combined with a passive amplifier section 320, where the passive amplifier section includes curved

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waveguide portion 340. The curved waveguide portion intersects output facet 195 at an oblique angle. Both the waveguide curvature and oblique intersection significantly reduces the amount of light reflecting from the output facet back into the amplifier and laser. Active-passive junction 330 is preferably oblique to a centerline of wave guide 105 so that any reflections from this interface coupling back into the amplifier and laser will be reduced. However, alternate embodiments may have active-passive junction 330 substantially normal to a centerline of the waveguide.

FIG. 3B shows an alternate embodiment where the amplifier active section has been segmented into a plurality of active sections in order to increase the amplifier output power and reduce a noise figure. In this embodiment shown in FIG. 3B, the amplifier active section is segmented into two amplifier active sections 310 that may be independently controllable. Other embodiments have more than two amplifier active sections. This segmenting of the amplifier enables the use of different bias points for the different sections. Having a plurality of amplifier stages allows higher saturated output powers to be reached with better noise performance.

FIG. 3C shows an alternate embodiment where a waveguide portion in the amplifier active section is flared, or tapered, to increase the saturated output power. Flared waveguide portion 350 increases the amplifier active volume as compared to the embodiment shown in FIG. 3A and decreases the photon density. To accomplish this effectively without introducing significant fiber coupling difficulties it is preferable to use an adiabatic flare, wherein there is no energy transfer across optical modes over the flare to a wider waveguide cross-section. In a preferred embodiment, a second flared-down section 355 to a narrow waveguide cross-section is positioned in the amplifier optically passive section 320 since it is difficult to couple effectively from a wide waveguide into a single mode fiber at output facet 195. In a preferred embodiment, such a flared-down portion is before a curved waveguide portion 340, otherwise, higher order modes will be excited when curving the wide waveguide. In the embodiment shown in FIG. 3C, active-passive junction 330 is angled so that any reflections from this interface coupling back into the amplifier and laser will be reduced.

FIG. 3D shows another embodiment including a waveguide mode adapter. A waveguide mode adapter is preferred in many embodiments to enlarge the optical mode near output facet 195 so that it is more closely matched to the mode in an optical fiber that, as an element in a communications system, may carry the light away from the output facet. Including a waveguide mode adapter thus reduces the fiber coupling loss and increases the alignment tolerances between laser assembly 100 (see FIG. 1) and an optical fiber of another system. An embodiment of a waveguide mode adapter includes a section of passive waveguide wherein the waveguide's cross sectional is varied to expand the waveguide optical mode in an adiabatic manner.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration

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and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is:

1. A method of generating an optical signal, comprising: providing a diode laser assembly including an epitaxial structure formed on a substrate, a laser and an amplifier formed in the epitaxial structure, the laser including first and second reflectors, a gain section and a phase section, the gain section and the phase section each being positioned between the first and second reflectors to produce a tunable laser output therefrom, at least a portion of the laser and an amplifier sharing a common waveguide formed in the epitaxial structure, wherein at least a portion of the common waveguide is curved to reduce reflections from an output facet; coupling the laser output into the amplifier along the common waveguide; and generating an optical signal from the amplifier in response to the coupled laser output.
2. The method of claim 1, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.
3. The method of claim 1, wherein the curved portion of the common waveguide reduces an amount of light reflecting into the amplifier and laser.
4. The method of claim 1, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.
5. The method of claim 1, wherein laser output is tunable over a tuning range while maintaining a substantially constant output power.
6. The method of claim 1, wherein laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.
7. The method of claim 1, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.
8. The method of claim 1, wherein the optical signal is generated while minimizing back reflections into the laser.
9. The method of claim 1, wherein the optical signal is generated while alternating at least one optical mode in the amplifier.
10. The method of claim 9, wherein altering the optical modes is an adiabatic mode expansion.
11. The method of claim 1, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.
12. The method of claim 1, wherein the curved portion of the common waveguide intersects the output facet at an oblique angle.
13. The method of claim 12, wherein both the curved portion of the common waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.
14. A method of generating an optical signal, comprising: providing a diode laser assembly including first and second semiconductor layers in an epitaxial structure, a waveguide formed between the first and second semiconductor layers in the epitaxial structure, and a laser and an amplifier formed in the epitaxial structure, the laser including a gain section and a phase section each being positioned between two grating sections to pro-

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duce a tunable laser output therefrom, wherein at least a portion of the waveguide is curved to reduce reflections from an output facet;

coupling the laser output into the amplifier along the waveguide;

propagating the laser output in a tapered section of the waveguide in the amplifier to increase saturated output power; and

generating an optical signal from the amplifier in response to the propagated laser output.

15. The method of claim 14, wherein the optical signal is generated while controlling an intensity of the laser output and maintaining a constant laser wavelength.

16. The method of claim 14, wherein the laser output is tunable over a tuning range while maintaining a substantially constant output power.

17. The method of claim 14, wherein the laser output is tunable over a tuning range of at least 15 nm while maintaining a substantially constant output power.

18. The method of claim 14, wherein the optical signal is generated while alternating a propagation direction of the laser output within the amplifier.

19. The method of claim 14, wherein the optical signal is generated while minimizing back reflections into the laser.

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20. The method of claim 14, wherein the optical signal is generated while altering at least one optical mode in the amplifier.

21. The method of claim 20, wherein altering the optical modes is an adiabatic mode expansion.

22. The method of claim 14, wherein the optical signal is generated while selectively exciting waveguide modes in the amplifier.

23. The method of claim 14, wherein the curved portion of the waveguide reduces an amount of light reflecting into the amplifier and laser.

24. The method of claim 14, wherein the curved portion of the waveguide intersects the output facet at an oblique angle.

25. The method of claim 24, wherein both the curved portion of the waveguide and the oblique angle reduce an amount of light reflecting from the output facet back into the amplifier and laser.

26. The method of claim 14, further comprising a waveguide mode adapter to enlarge an optical mode near the output facet, so that it is more closely matched to a mode in an optical fiber.

* * * * *